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Cable Ageing in Nuclear Power Plants

Report on the First and Second Terms (2012-2017) of the NEA Cable Ageing Data and Knowledge (CADAK) Project

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NUCLEAR ENERGY AGENCY
COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

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ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

The OECD is a unique forum where the governments of 36 democracies work together to address the economic, social and environmental challenges of globalisation. The OECD is also at the forefront of efforts to understand and to help governments respond to new developments and concerns, such as corporate governance, the information economy and the challenges of an ageing population. The Organisation provides a setting where governments can compare policy experiences, seek answers to common problems, identify good practice and work to co-ordinate domestic and international policies.

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NUCLEAR ENERGY AGENCY

The OECD Nuclear Energy Agency (NEA) was established on 1 February 1958. Current NEA membership consists of 33 countries: Argentina, Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Korea, Luxembourg, Mexico, the Netherlands, Norway, Poland, Portugal, Romania, Russia, the Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The European Commission also takes part in the work of the Agency.

The mission of the NEA is:

- to assist its member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally sound and economical use of nuclear energy for peaceful purposes;
- to provide authoritative assessments and to forge common understandings on key issues as input to government decisions on nuclear energy policy and to broader OECD analyses in areas such as energy and the sustainable development of low-carbon economies.

Specific areas of competence of the NEA include the safety and regulation of nuclear activities, radioactive waste management and decommissioning, radiological protection, nuclear science, economic and technical analyses of the nuclear fuel cycle, nuclear law and liability, and public information. The NEA Data Bank provides nuclear data and computer program services for participating countries.

COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

The Committee on the Safety of Nuclear Installations (CSNI) is responsible for the Nuclear Energy Agency (NEA) programmes and activities that support maintaining and advancing the scientific and technical knowledge base of the safety of nuclear installations.

The Committee constitutes a forum for the exchange of technical information and for collaboration between organisations, which can contribute, from their respective backgrounds in research, development and engineering, to its activities. It has regard to the exchange of information between member countries and safety R&D programmes of various sizes in order to keep all member countries involved in and abreast of developments in technical safety matters.

The Committee reviews the state of knowledge on important topics of nuclear safety science and techniques and of safety assessments, and ensures that operating experience is appropriately accounted for in its activities. It initiates and conducts programmes identified by these reviews and assessments in order to confirm safety, overcome discrepancies, develop improvements and reach consensus on technical issues of common interest. It promotes the co-ordination of work in different member countries that serve to maintain and enhance competence in nuclear safety matters, including the establishment of joint undertakings (e.g. joint research and data projects), and assists in the feedback of the results to participating organisations. The Committee ensures that valuable end-products of the technical reviews and analyses are provided to members in a timely manner, and made publicly available when appropriate, to support broader nuclear safety.

The Committee focuses primarily on the safety aspects of existing power reactors, other nuclear installations and new power reactors; it also considers the safety implications of scientific and technical developments of future reactor technologies and designs. Further, the scope for the Committee includes human and organisational research activities and technical developments that affect nuclear safety.

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Executive summary

The NEA Cable Ageing Data and Knowledge (CADAK) Project is the continuation of the cable ageing part of the NEA Stress Corrosion Cracking and Cable Ageing Project (SCAP). In 2012, eight NEA member countries – Belgium, Canada, France, Japan, the Slovak Republic, Spain, Switzerland and the United States – joined the CADAK Project to pool their knowledge into a common database.

The CADAK Project aims to establish the technical basis for assessing the qualified life of electrical cables in light of the uncertainties identified following the initial (early) qualification testing. This research will investigate the adequacy of the margins and their ability to address the uncertainties. The project was financed through contributions from each participating NEA member country. The first term work concentrated on continuing the construction of the database for data gathering and defining the methods for national co-ordinators supplying data and documents presenting the results of the ongoing research and test programmes.

The database facilitates data entry as well as database interrogation. The knowledge base allows for capturing, sharing, transferring, storing and utilising technical information on cable degradation mechanisms, relevant R&D results, and national codes and standards for design and construction and in-service inspection. The CADAK database includes over 1 300 records divided among those ten parts forming the database structure. The knowledge base includes almost 275 country specific collections of documents in ten different areas.

For the second term, the analysis of cable data was one of the CADAK Project goals; however, there are large variations of cable types and insulation materials in the database and differences in plant level application related to the use of cables. A large part of CADAK data originates from the SCAP project and another large part of the data was provided from countries that no longer participated in CADAK during phase two. The participating countries were Canada, Germany, the Slovak Republic, Switzerland and the United States. The mentioned variation in cables and detailed level differences in cable use include: plant designs, local environmental conditions between units with the same design type and series, supplying procedures, use of materials and manufacturing methods and storage times. These have a remarkable influence on the lifetime of cables. The completion of data collection actions for all the cable types in the database was not possible with the remaining countries in the project. Based on all these variations and uncertainties of existing cable data it was recognised that the amount of work and resources needed for the comprehensive analysis was so large that such an analysis for the cable data in CADAK database was not possible during phase two.

As an overall conclusion of the project, it is foreseen that demonstrating adequate cable performance and ageing management in normal operation and post-accident services for a lifetime over 60 years, or even more, will be a challenge. It appears that the approval of a lifetime over 60 years or longer needs new representative test results and cable material

research as well as more operational experience analysis for recognising the critical subjects and targets for additional inspections, assessments and preventive maintenance. The following recommendations are defined for the future work in the field of cable ageing:

- In future, the key objectives of work with cable ageing will be to encourage all countries to support the multilateral exchange of recent research data and operating experience of cables. If additional experimental studies allow the identification of ageing phenomena (generic issues) or improvement of associated kinetics and influence criteria, it should be published.
- It is recommended that all international working parties in the field of cable ageing exchange information with other international organisations (e.g. IAEA) to prevent duplication of research efforts. It is also recommended to arrange a common NEA/IAEA workshop in a the coming years, when the ongoing cable research activities of NEA member countries are completed.
- The information obtained from the decommissioned nuclear power plants (NPPs) should be used to verify, validate and/or confirm the assumptions used in the current qualification for cables that are important to safety. Projects to collect cable samples removed from decommissioned NPPs should be used to verify whether these cables are qualified for additional qualified life beyond 40 years and beyond 60 years, or even more. The usefulness and representativeness of cable samples of the decommissioned NPPs could be a good topic for future research or discussion in international decommissioning programmes.

This project report describes the final status of the CADAK database after SCAP work and the first and second term (2012-2017) of the Cable Ageing Data and Knowledge (CADAK) Project.

Definitions

CADAK Database	Database + knowledge base
Database	Cable-specific information database
Knowledge Base	Database with the collection of international and country specific documents on cables

List of abbreviations and acronyms

AECL	Atomic Energy of Canada Limited
AM	Ageing management
AMR	Ageing management review
AMP	Ageing management programme
BIS	Broadband impedance spectroscopy
BWR	Boiling water reactor
CADAK	Cable ageing data and knowledge
CI	Condition indicators
CODAP	Component Operational Experience Degradation and Ageing Programme (NEA)
CNSC	Canadian Nuclear Safety Commission
CM	Condition monitoring
CSN	Consejo de Seguridad Nuclear (Spain)
CSNI	Committee on the Safety of Nuclear Installations (NEA)
CSPE	Chlorosulfonated polyethylene
DBA	Design-basis accident
DMA	Dynamic mechanical analysis
EAB	Elongation at break
EBP	Extra-budgetary programme
EDF	Electricité de France
EPDM	Ethylene propylene diene monomer
EPR	Ethylene propylene rubber
EPRI	Electric Power Research Institute (United States)
ETFE	Ethylene tetrafluoroethylene
EQ	Environmental qualification
EVA	Ethylene vinyl acetate
FTIR	Fourier-transform infrared (spectroscopy)
HFFR	Halogen-free flame retardant
IAEA	International Atomic Energy Agency
IFE	Institute for Energy Technology (Belgium)
LIRA	Line impedance resonance analysis

LOCA	Loss-of-coolant accident
LV	Low voltage
MSLB	Main steam line break
MV	Medium voltage
NEA	Nuclear Energy Agency
NIR	Near infrared reflectance
NMR	Nuclear magnetic resonance
NPD	Nuclear power demonstration station
NPPs	Nuclear power plants
OIT	Oxidation induction time
OITM	Oxidation induction time method
OITP	Oxidation induction temperature
OPDE	Piping failure data exchange
PE	Polyethylene
PRG	Project review group
PSI	Paul Scherrer Institute (Switzerland)
PSR	Periodic safety review
PVC	Polyvinyl chloride
PWR	Pressurised water reactor
SBR	Styrene butadiene rubber
SCAP	Stress Corrosion Cracking and Cable Ageing Project (NEA)
SCC	Stress corrosion cracking
SIR	Silicone rubber
TDR	Time domain reflectometry
TGA	Thermogravimetric analysis
TLAA	Time limited ageing analysis
USNRC	United States Nuclear Regulatory Commission
WGIAGE	Working Group on Integrity and Ageing of Components and Structures (NEA)
TS	Tensile strength
XLPE	Cross-linked polyethylene
XLPO	Cross-linked polyolefin

1. Introduction

1.1. Background

The number of ageing nuclear power plants (NPPs) is increasing in NEA member countries. Accordingly, maintenance programmes, in-service inspection and testing of structures, systems and components important to safety have been implemented to ensure that levels of reliability and effectiveness remain in accordance with the design assumptions. This is often being done using an integrated ageing management strategy based on state-of-the-art technology.

Ageing effects, especially material degradation, have progressively been experienced worldwide since the start of nuclear power plant operation. Material degradation is expected to continue as plants age and operating licences are extended. It is clear that unanticipated and unmanaged structural degradation could result in significant loss of safety margins, undermining public confidence and straining the resources of both regulatory authorities and the operators.

For regulatory authorities, it is important to verify the adequacy of the ageing management methods applied by the licensees, based on reliable technical evidence. Degradation of cable insulation were selected as one of the focus areas of the of SCAP project (2006-2010) due to its implications for nuclear safety and its relevance for plant ageing assessment.

In December 2010, the CSNI agreed to support two SCAP follow-up activities, that being the convening of an experts meeting on the cable ageing database and secondly, the convening of an experts meeting on the merging of the SCC and OPDE database projects to become the CODAP (Component Operational Experience, Degradation and Ageing Programme) project. The CADAK Project followed the cable ageing part of the NEA SCAP Project.

In 2012, eight NEA member countries joined the CADAK Project to pool their knowledge into a common database. The project was financed through economical contributions from each participating member country to NEA. The objectives of the CADAK Project are to establish the technical basis for assessing the qualified life of electrical cables in light of the uncertainties identified following the initial (early) qualification testing. This research will investigate the adequacy of the margins and their ability to address the uncertainties.

This report summarises the project results of the CADAK database project during the two three-year terms: First term: 2012 to 2014 and second term: 2015 to 2017.

1.2. Objective

The general objective of this internationally co-ordinated project is to share the corporate knowledge, operation and research experience so as to better understand the degradation mechanisms and identify effective techniques and technologies to manage and mitigate active cable degradation in NPPs. This helps regulators and operators to enhance ageing management.

Technical objectives of the CADAK database project are as follows (Terms and Conditions for Project Operation – 2011-2014):

a) to establish the technical basis for assessing the qualified life of electrical cables in light of the uncertainties identified following the initial (early) qualification testing. This research will investigate the adequacy of the margins and their ability to address the uncertainties.

b) to edit for a number of member countries cable data and information into the system e.g. technical standards being applied in the qualification of cables and inspection methods being used regularly.

c) to estimate the remaining qualified lifetime of cables used in NPPs. The cable Condition-Monitoring Techniques shared by the participants within CADAK will become an up-to-date encyclopaedic source to monitor and predict the performance of numerous unique applications of cables.

d) to analyse the information collected to develop topical reports in co-ordination with the NEA CSNI Integrity and Ageing of Components and Structures Working Group (WGIAGE).

The technical objectives were written to be followed in the long-term work with CADAK database. In years 2012-2014 during the first term CADAK the focus of the CADAK project was in developing the database and knowledge base structure for effective data collection from the surveillance and test programmes as well as the ongoing research activities in member countries.

During the second term in years 2015 -2017 the CADAK project was continuing the work with same objectives. An additional goal during for CADAK term two was to collect information on ageing effects of the electrical penetrations into the CADAK database; however, the goal was not achieved.

1.3. Project organisation

The project participants are experts in the fields of cable ageing and come from regulators, industry and research institutions. They provide the relevant information and perform the assessments needed for the proper execution of the programme.

The NEA Project Secretariat runs the project with assistance from the operating agent.

The Project Review Group (PRG) is responsible for carrying out the program of work, in co-operation with NEA and the operating agent, and ensuring the quality and timeliness of the reporting within and outside the project.

The Operating Agent work to ensure the consistency of the data contributed by the participating countries. They verify whether the information provided complies with the CADAK Coding Guidelines. They also verify the completeness and accuracy of the data, and maintain and distribute copies of the database and knowledge base.

Participation in the project is open to the government of any country, whether or not they are a member of the OECD, or to any national agency, public or private organisation designated by such government provided the government agrees with the terms of reference which were specified during the initial meeting. Each member country nominates a national representative for the PRG who is responsible for the administration of the project within his/her respective country.

Each participating country has submitted data and documents through its national representative. The data has been entered according to a specified format which was specifically developed for the data- and knowledge base and which is explained in the Coding Guidelines and the Quality Assurance Program for the PRG. The cable database and knowledge base are password protected, and the contents and data analysis results are distributed only among active working group members under the project terms of reference.

1.4. Scope

The scope of this project involves the continued development and population of the database and knowledge base that address common elements in the management of ageing and mitigation of failures for cables: study of ageing effects, investigation of failure mechanisms, mitigation of influencing factors, prediction of conditions for replacement, safety assessment of cables, environmental qualification (EQ) and condition-monitoring methodology and its validation.

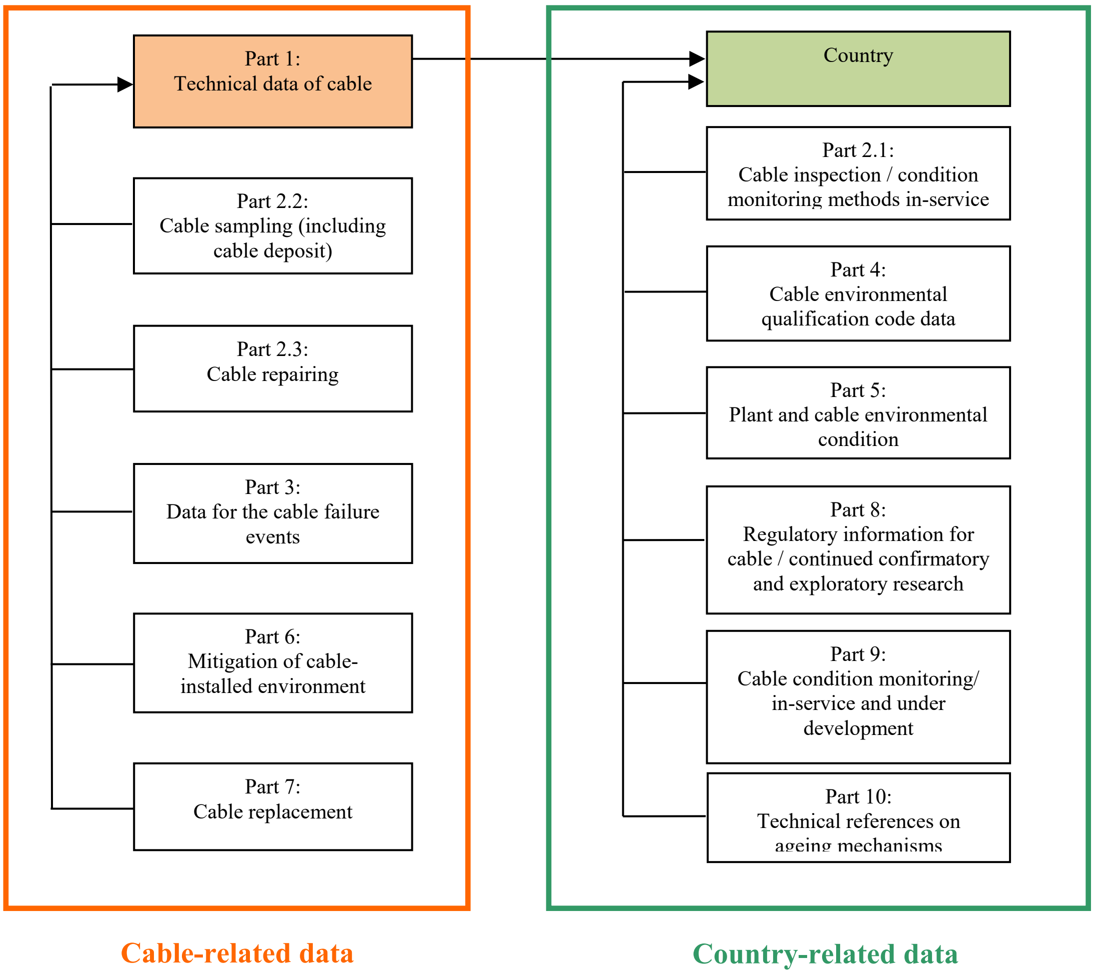
The second term of CADAK has same general goals than in first term; however, the additional goal to provide ageing effects of the electrical penetrations into the CADAK database was not reached during second term.

2. Database overview

2.1. Introduction

The database and the knowledge base work in CADAK is a continuation of the work that was performed under the NEA SCAP project (2006-2010), and builds on the same philosophy, principle structure and populated data. Both the database and knowledge base are organised in ten main parts to document all the details of the cable including design, qualification, maintenance, condition-monitoring and continuing research. The principle structure and the parts are shown in Figure 2.1.

Figure 2.1. The principle structure of CADAK Database and knowledge base



2.2. Intended use

All information in the database and knowledge base of CADAK is made available for all CADAK members through a dedicated web-interface, and without any restrictions or imposed guidelines.

2.3. Database and knowledge base development

2.3.1. Database development

The database is organised as a relational database, originally operating on MySQL software, and was built from data collected by the different member country participants. Database entries are managed through dedicated web entry sheets, originally handled through zope application server and plone content management system. In 2017, the process of migrating CADAK application software to modern database- and web-technology software was initiated (ref. Section 2.6.2). During the CADAK project, population of the database has continued, and there has also been made changes to the detailed item structure for Part one – Technical data of cable. In addition, the CADAK term two member countries discussed the possibility to add more ageing-components to the database, and the design of a new main part related to cable penetration was initiated (ref. Section 2.6.1). It has also been put greater focus on the knowledge base during this period. When the CADAK project is being completed, the database includes 1 338 records divided among those 10 main parts forming the CADAK database structure.

2.3.2. Knowledge base development

The knowledge base consists of a collection of document files, and was built from data collected by member participants. The former SCAP Cable Working Group evaluated the information in the database and identified subject areas that were of great significance and would be of great use to current nuclear operators and regulators, and classified them as the knowledge base. The assessment began with the identification of the essential elements to be in the knowledge base. The former SCAP Cable Working Group examined and reviewed the data collected in the database and extracted information, leading to a certain number of conclusions. During CADAK, participating member organisations have continued to populate the knowledge base. In addition, all document files provided as attachments to database records have been transferred to the knowledge base, leading to 275 separate document files in the knowledge base. These document files are accessible through the CADAK knowledge base web-interface.

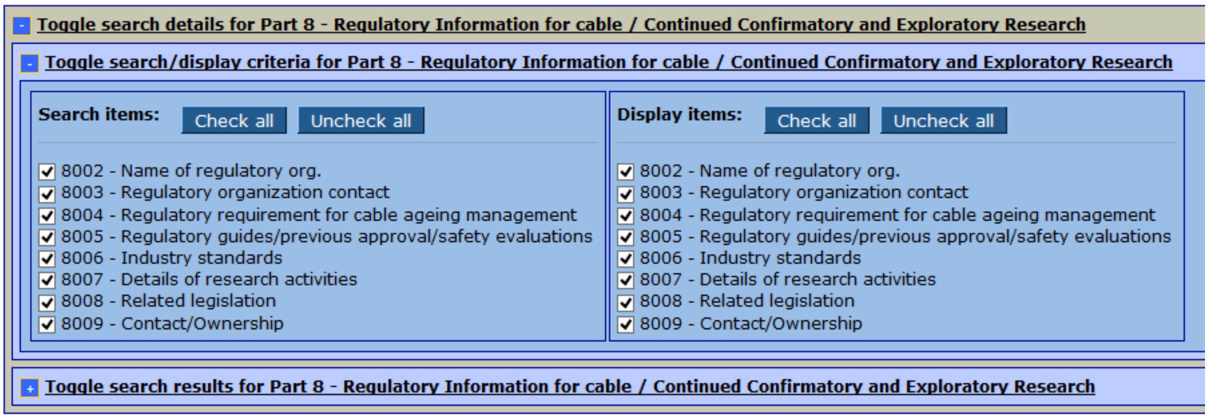
2.4. Database search capability

The cable database search tool allows fast access to desired information in any part of the database. The search tool opens up for multi-part/multi-country searches, with possibilities for tailor-made search and display criteria. Figure 2.2 shows the entry point for the search tool, with panels for choosing main search criteria as parts, countries and search strings.

Figure 2.2. Entry point for database search tool

A dedicated search/display filtering panel for each part opens up for search and result display filtering. See Figure 2.3 for an example from "Part eight: Regulatory information for cable/Continued confirmatory and exploratory research".

Figure 2.3. Detailed search/display filtering panel



An example of a database search result in Part 8 – Regulatory information for cable/Continued confirmatory and exploratory research is shown in Figure 2.4. The search outcome shows e.g. applicable cable regulations, organisation and contact name for the regulator. Detailed record information, based on the search results and member access rights, is made available through dedicated pushbuttons.

Figure 2.4. An example of a search result from Part eight – Regulatory information for cable/Continued confirmatory and exploratory

Toggle search results for Part 8 - Regulatory Information for cable / Continued Confirmatory and Exploratory Research

First | Previous | Next | Last | Sort by: ID # | Direction: ↑ ↓

Showing search results no. 1 to 10 of 17 search results.

Item #		8001	8002	8003	8004	8005	8006	8007	8008	8009
Select	ID #	Country	Name of regulatory org.	Regulatory organization contact	Regulatory requirement for cable ageing management	Regulatory guides/previous approval/safety evaluations	Industry standards	Details of research activities	Related legislation	Contact/Ownership
◉	1		Ministry of Economy, Trade and ...	http://www.nisa.meti.go.jp/eng ...	Technical evaluations of effec ...	The regulatory guide for the e ...	There is "Recommendations for ...	To establish cable ageing eval ...	For environmental qualificatio ...	
○	2		State office for nuclear safet ...	www.sujb.cz	qualification in compliance wi ...		CSN IEC 60780, IEEE 383		Czech Regulation 132/2008 (in ...	
○	3		Consejo de Seguridad Nuclear (...	jfc@csn.es	Specific requirement of Operat ...	During plant service life, (40 ...	Spanish NPP are not requiered ...	UNESA (Spanish Association of ...		
○	5		United States Nuclear Regulato ...	Thomas.Koshy@nrc.gov	10CFR50.49	NUREG-1801, Revsion 1		We are considering research to ...		Thomas.Koshy@nrc.gov
○	7		National Nuclear Energy Genera ...	http://www.energoatom.kiev.ua/ ...	Program of NPP Cable Aging Man ...	Regulatory guide. Procedure of ...				
○	9		National Nuclear Energy Genera ...	www.energoatom.kiev.ua	Program of cable environment m ...	Program of cable environment m ...				
○	10		National Nuclear Energy Ge ...	www.energoatom.kiev.ua	Requirement to the procedure o ...	Procedure of the control cable ...				
○	11		Canadian Nuclear Safety Commis ...		Licence Condition on Environme ...	See item 8004	CSA N290.13-05 is not specific ...	The Canadian Nuclear Safety Co ...	A related legislation has not ...	
○	12		KTA (Nuclear Safety Standards ...	http://www.kta-gs.de	Cable qualification is establi ...		For more technical details the ...		References (current versions o ...	
○	13		BfS (The Federal Office for Ra ...	http://www.bfs.de	RS-Handbook (Handbook on Nucle ...					

Show selected search result | Update selected search result

2.5. New features during CADAK term one

The new features added into the original database (based on SCAP project work [2]) are listed in this chapter and covers the following areas:

- Structure of the technical part of the database
- Knowledge base part
- Web-interface

2.5.1. Structure of the database

- Part one – Technical data of cable: Items «insulation material» and «other insulation material» have been made mandatory.
- Continued population of the database.

2.5.2. Knowledge Base

- All attachments in CADAK database have been copied to the corresponding sections in knowledge base.
- Extended population of the knowledge base.

2.5.3. Web-interface

- Extended menu field by introducing top-level information folders:
  - Actions
  - Database
  - Knowledge base
  - Meetings
  - National activities
  - Related links
  - Reports
  - Standards
  - Upcoming events
- Introduced CADAK Attention and Contacts fields

2.6. Planned extension of the database structure and migration to a new software platform during term two

2.6.1. Structure extension – Cable penetration

The CADAK term two member countries discussed the possibilities to introduce possible ageing effects of the electrical penetrations into CADAK database, knowledge base and web-interface. Possibilities to introduce even more qualified components into the database, knowledge base and web-interface were also discussed, but the CADAK PRG decided to postpone these plans.

The structure building of a new main part eleven – Cable Penetration was therefore initiated, consisting of the two sub-parts:

- 11.1 – General information/Generic data from supplier
- 11.2 – Technical specification data.

However, the final implementation of part eleven – Cable Penetration was not completed as the CADAK project was terminated by the end of 2017.

2.6.2. Migration to a new software platform

Development of the NEA CADAK database & knowledge base application was started in 2006 as part of the Stress Corrosion Cracking and Cable Ageing Project (SCAP). It was built on a software platform consisting of a Debian Linux v6.0 operating system, Zope Application Server v2.0 and Plone Content Management System v3.02.

The CADAK application itself and the underlying software tools were tailor-made for its purpose. Structural differences in newer software versions made upgrades difficult and thus making the system versions deprecated. This caused limitation and put constraints and reduced flexibility when it comes to managing records and documents in the database and knowledge base. The limitations made it difficult to scale data quantities, increase number of users, introduce new and user friendly functionality and to provide respectable response times.

The deprecated system also caused a considerable security risk, and was vulnerable to cyber-attacks. This vulnerability brought a lot of attention to the operating agent’s digital infrastructure, and violated digital security. It was therefore not desirable for the operating agent to continue these software modules. An upgrade to newer versions would have had to incur a restructuring and rewriting of the existing application, which would have been both time and cost consuming and still remain old and unsecure technology.

As a consequence the operating agent planned to stop using the zope/plone technology for its web-applications, and started a process of restructuring its digital infrastructure, based on today's and future challenges. Cyber threats and cyber security were keywords, and OA were about to change business model for dealing with web technology. To be in line with the operating agent’s new digital policy, and up to date on software- and development tools, this caused a need to migrate the CADAK application to a new and modern platform. This could be achieved by adopting modern software and development tools like:

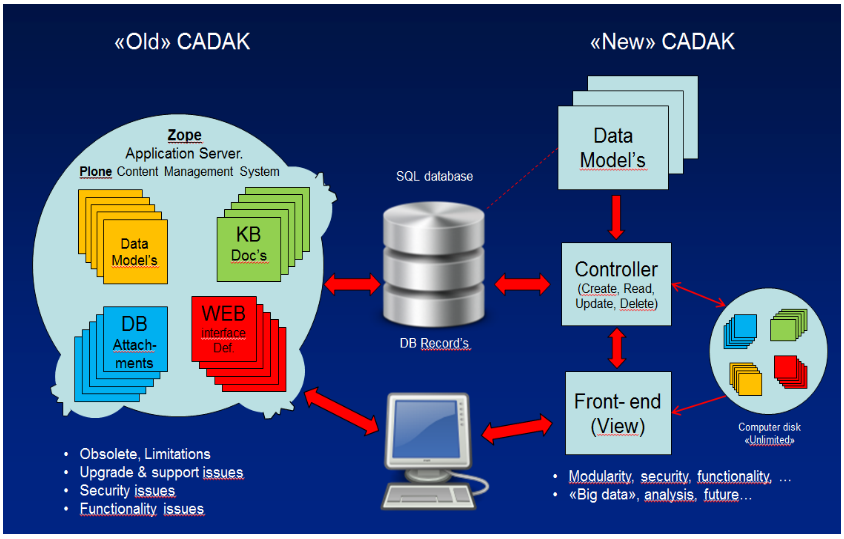
a) Microsoft Visual Studio Community 2015
b) Microsoft SQL Server (MSSQL Express)
c) Microsoft.NET Framework

d) ASP.NET
e) Microsoft MVC 5 Entity Framework.

During 2017, the development of a migrated CADAK system application was initiated, with high degree of modularity, meeting today's security requirements and opens up the possibility for future extensions like e.g. improved analysing methods, big-data, data import/export. However, the implementation phase was never reached as the CADAK project was terminated by the end of 2017. Nevertheless, a simplified system (read-access) will be provided to allow CADAK member countries to access database and knowledge base in an offline post-CADAK-phase.

Figure 2.5 shows the conceptual models for the old deprecated zope/plone based configuration, and the planned new modular configuration based on modern software- and development tools.

Figure 2.5. Old and new conceptual models for the migrated software platform



3. Environmental condition monitoring

In the nuclear field, where cables related to the safety of the plant are qualified before installation for the expected life (e.g. 40 years) the effect of the particular adverse environment conditions (high radiation, humidity and temperature), especially during and after design basis accidents (DBAs), is an important issue for the assessment of the condition of installed cables.

Main ageing factors (stressors) to be monitored are temperature (including self-heating) and radiation. Other factors to be considered include humidity, electrical fields, corrosive environment in specific areas and mechanical stresses due for example bending or vibration.

These factors contribute to the degradation of the mechanical and electrical properties of cables. Testing methods aim to determine the progress of ageing. Main effort is performed on insulation regarding the fact it plays a major role in electrical properties of cables.

Monitoring of environmental conditions in the nuclear power plant that may adversely affect cable performance can provide valuable insight when determining cable life. It is strongly needed to determine equipment which is submitted to the highest stress. Performing tests on these cables permits to have valuable information on their degradation and to gain in confidence concerning the degradation of other cables. Outer sheath plays generally the role of mechanical protection and limit the exposure of insulation e.g. corrosive fluids or mineral oils.

The significant stressors in normal operation are the following:

- Temperature including temperature increase due to self-heating (resistive effect)
- Radiation
- High humidity or submergence conditions (in specific areas)
- Mechanical constraints

In some high voltage cables, electrical fields may accelerate ageing mechanism in presence of other stressors (for example humidity).

Operating feedback is needed to improve the quality of environmental condition monitoring.

A lot of countries monitor environmental conditions in containment and in some specific areas outside of containment. A synthesis of measurements done in Japanese units (in containment) updated in 2014 is presented in Table 3.1 below.

Table 3.1: Summary of plant environmental condition for Japanese nuclear power plants (Additional date to table 3.3.5-2 of NEA/CSNI/R(2010)15 – Reference [2]

Plant	Temperature			Dose rate		
	Tool	Number of measurement points	Maximum temperature (℃)	Tool	Number of measurement points	Maximum dose rate (Gy/h)
BWR, BWR-5	Data loggers and labels for thermometry	140(163)	52.5	Alanine dosimeters	159	0.404
BWR, BWR-5		94(94)	69		95	0.086
BWR, BWR-5		157(167)	70.4		167	0.087
BWR, BWR-5		28(75)	60.4		78	0.453
BWR, BWR-5		223(100)	71.9		100	0.1206
BWR, BWR-5		158(47)	59.8		87	0.2516
BWR, ABWR		88(14)	62.5		92	0.144
BWR, ABWR		93(82)	52.7		98	0.1056
BWR, ABWR		103(74)	57.6		106	0.092
PWR, 2-loop		29(33)	57.9		22	0.255
PWR, 3-loop		36(17)	59.3		36	0.341
PWR, 4-loop		34(25)	46.3		24	0.068
PWR, 4-loop		40(54)	44.1		60	0.271

For PWR, maximum temperature is generally expected for power cables of motor operated valves located on or nearby primary circuit (e.g. hot loop and pressuriser areas). Maximum dose rate is around 0.2 Gy/h, except in area near the reactor pressure vessel. For boiling water reactor (BWR) maximum temperatures and dose rates are usually somewhat higher based on smaller size of containment. There are somewhat variations with maximum levels of temperature and radiation during power operation, depending on plant design features related to air conditioning and radiation protection structures inside of containment.

4. Condition indicators

Following IAEA Nuclear Energy Series No: NP-T-3.6 [6] the condition indicator(s) will be used to track the ageing of the cables and to determine if aged cable is still able to operate under accident conditions. An important characteristic of a useful condition indicator is that it demonstrates a trend that changes monotonically with degradation and can be correlated with the safety-related performance in-service conditions (including accident conditions). For example, the parameters used as condition indicators could monitor the change in the chemistry of the material (e.g. polymer chain degradation, side reactions), monitor the mechanical properties (e.g. tensile elongation, hardness, compressive modulus), or monitor electrical properties of the material (e.g. dielectric properties or reflectometry properties). A large number of methods are available, but the condition indicators should be sensitive to the effects of ageing for the particular material and correlation between this degradation state and ability of aged cable to operate correctly in different service conditions (including accident conditions for which it shall be qualified).

For effective cable ageing management, it is important to identify cable information including cable type, material, critical parts which may be influenced by ageing stressors, ageing mechanism and its potential effects. Cable condition-monitoring method is determined based on the before mentioned information. Test and inspection frequencies are defined based on operating experience, on safety relevance of cable and on the trend of the selected indicators.

Different methods exist to perform condition monitoring of cables, e.g. visual inspections, indenter, time domain reflectometry (TDR), insulation resistance measurement, voltage test, elongation at break (EAB), Fourier-transform infrared (FTIR), near infrared reflectance (NIR), oxidation induction time (OIT) test, tan δ, etc.

Acceptance criteria are material dependent: e.g. a cable match by EAB, a level of more than 50%, voltage tests requirements fulfilled, TDR should be in the acceptable range, etc. Acceptance criteria should be, when possible, defined regarding characteristic of cables measured during qualification sequence just before accident test (e.g. just after ageing sequence).

The acceptance criteria for determining the end of residual life time of installed EQ cables are plant specific. The acceptance criteria should ensure that cables are able to successfully perform their safety-related demands during accident condition at the ageing level determined by the selected condition-monitoring techniques.

Condition monitoring can be done on cable samples that have been subject to representative operating conditions stressors. Measurement should be done on samples which are the most stressed what permits to interpolate the result for less stressed cables. Additional cable samples can be deposited to limit the use of operating cables see Figure 4.1.

Figure 4.1. Cable samples of Beznau NPP

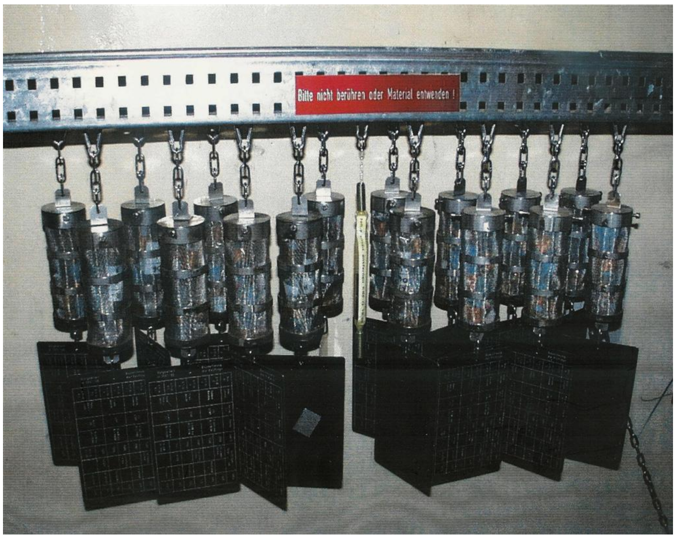
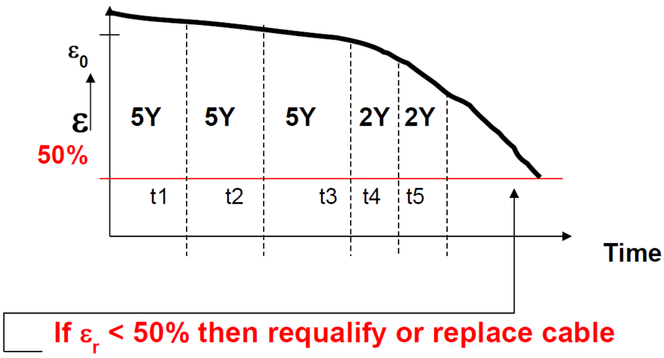


Figure 4.2. Cable ageing during test periods (principle curve)



ε_0 = level at the beginning of ageing (new cable) - Tensile test of samples every five years (all two years if significant changes)

Figure 4.2 presents an example for defining the intervals and criteria for the tensile tests on cables. The interval for the tensile test of cable samples is every five years. If the tensile test results decrease under the original tensile requirement for similar new cable the test interval is two years. In this example the accepetance criteria in the tensile tests for cables with original qualification is 50% of the original requirements.

Examples of ageing management tables for Coax/Triax and low-voltage power cables are shown in Table 4.1 and Table 4.2 below.

Table 4.1.: Examples of ageing management table for coaxial and triaxial cables used inside the containment vessel of Beznau nuclear power plant

Part	Material	Ageing Parameter	Ageing degradation	Possible Diagnose	Interval	Remark
Wire (connection)	Copper	Humidity Vibration	Corrosion bad contact	TDR Visual check	12 Y	
Insulation	EPDM EPR	Ambient temperature Service temperature Humidity Radiation	Embrittlement Discoloration Oxidation Cracks	Insulation resistance measurement Voltage test Cable deposit	5 Y	Compare with qualified life type test and samples at deposit
Strap	glass fiber	Radiation Service temperature	Embrittlement Discoloration			
Jacket	EPDM EPR	Ambient temperature Service temperature Humidity Radiation Spray (Bore acid)	Embrittlement Discoloration Oxidation Cracks	Visual check Infrared measurement Cable deposit	12 Y 5 Y	Compare with qualified life type test and samples at deposit

Table 4.2. : Example of ageing management table for low-voltage cables used in the containment vessel of Beznau NPP

Part	Material	Ageing Parameter	Ageing degradation	Possible Diagnose	Interval	Remark
Wire (connection)	Copper	Humidity Vibration	Corrosion bad contact	TDR Visual check	12 Y	
Insulation	EPDM EPR	Ambient temperature Service temperature Humidity Radiation	Embrittlement Discoloration Oxidation Cracks	Insulation resistance measurement Voltage test Cable deposit	5 Y	Compare with qualified life type test and samples at deposit
Strap	glass fiber	Radiation Service temperature	Embrittlement Discoloration			
Jacket	EPDM EPR	Ambient temperature Service temperature Humidity Radiation Spray (Bore acid)	Embrittlement Discoloration Oxidation Cracks	Visual check Infrared measurement Cable deposit	12 Y 5 Y	Compare with qualified life type test and samples at deposit

5. Ageing of cables

In the last 20 years some specific regulatory recommendations have been made concerning the pre-ageing of cables for the qualification tests to ensuring the safety margins of cables under design basis accident conditions. To ensure the scientific and technical basis of these recommendations a lot of countries have investigated ageing effect for cables in last 15 years. Ensuring the safety margins is especially important to the cables, which have to withstand the harsh environment, especially high thermal and radiation effects during accidents. Recent international research on cable qualification and ageing management (e.g. SCAP Project [2], IAEA Nuclear Energy Series, IAEA/NP-T-3.6 [6]) has raised an issue about "uncertainties" in the validity of cable EQ programmes performed in the past.

Experimental programmes have been performed in the last two decades in the U.S. (SANDIA), Japan (JNES/NRA), France (NPP) that lead to the following main sources of these uncertainties:

- Synergistic effects in the radiation & thermal ageing test sequence applied
- Acceleration factors used in the radiation & thermal ageing tests
- Dose rate effects
- Oxygen-starved LOCA chambers effects
- Non-conservative/incorrect activation energy values, used in Arrhenius equation
- Inverse temperature effects (semi-crystalline polymers XLPE, XLPO)

More recently, document SAND 2013-2388 "NPP cable materials: review of qualification and currently available ageing data for margin assessments in cable performance" [7], has been published. It gives a synthesis of these uncertainties issues.

Based on these experimental programmes the following recommendations can be expressed:

- Perform condition monitoring and obtain condition indicators (mechanical, chemical /Oxidation Induction Temperature/electrical/dielectric strength, Tan delta method) during and at the end of ageing condition test sequence.
- Thermal ageing time shall not be reduced too much and temperature shall not be too high to ensure representativeness of accelerated thermal ageing (>> 100hours).
- The dose rate for radiation ageing should be as low as can be accommodated within reasonable cost and duration of the test noting that several insulation materials do not exhibit homogenous degradation when radiation dose rates are higher than 100Gy/h (10 000 rad/hour).
- Regarding the fact that ratio of oxidation is higher for low dose rate, total dose applied during ageing sequence shall be adapted accordingly.

- The LOCA-test chamber used in cable qualification tests should provide methods for continuous supply of oxygen to prevent non-homogeneous degradation in an oxygen-starved environment.
- The temperature and dose rate for radiation ageing and for radiation in post-accident phase should be chosen considering that oxidation is a primary ageing mechanism for most age sensitive equipment and degradation depends on both thermal stress and radiation.
- Humidity shall be taken into account.
- Operational ageing (thermal and radiation dose) rates should ensure homogeneous degradation of the test samples.
- Limits for the temperature and dose rate, specifications of the activation energy, and ageing time should be properly evaluated.
- For certain material (polyolefin) inverse temperature effect shall be taken into account (faster degradation at lower temperature and with a given dose rate for specific material).
- For radiation ageing, it is always better to apply a total dose higher than the dose corresponding to the expected service life, so as to obtain a margin taking all these elements into account.
- Sequential tests can be less penalising than performing simultaneous thermal and irradiation ageing. In case of using sequential test, the most degrading sequence shall be chosen.

Currently the nuclear community is concerned about the potential effects of the uncertainties issue on the current qualification status of the cables installed in the operating NPPs.

This issue could impact the validity of initial qualification programmes. In Europe, it should be assessed in the frame of periodic safety review (PSR) of the plants (every ten years) and for the lifetime extension targets.

Regarding uncertainties sources, many countries are recommending initiating investigation about usable condition indicators to track ageing of insulation. These methods should be used in the following years by choosing properly candidate (and if possible on an anticipated way) samples coming from operating or dismantled plants.

Main stressors (temperature and irradiation) that cables have experienced during their operating life, have to be taken into account in the choice of samples (what needs monitoring of ambient conditions). In many countries these programmes or researches are ongoing (Canada, Spain, United States, France). For more details please refer to Section 7. (R&D).

6. Ageing of cable penetrations

For an ageing programme it is important, that all relevant components which have ageing mechanism are monitored. Therefore, in the term two the CADAK team selected the cable penetration as part of the cable data programme. The cable penetrations data in this report and in the CADAK is emphasising into the cable penetrations of the primary containment, which are most important from ageing point of view.

These penetrations are used for electrical cable access through the containment boundary and their main purpose is to provide a pathway for electrical links through the containment boundary while keeping an effective seal around the cables between both sides of the containment boundary.

The cable penetration itself has to be tested before installation against temperature resistance, pressure resistance, dose rate, leakage rate and earthquake resistance. After installation the leakage rate of penetration is periodically tested. In NPPs using the leakage budget method the total leakage rate of containment is used as approval method of the measured leakage rates.

For an EQ cable penetration, similar approach is adopted like for EQ cable. For instance, applicable qualification methods (such as analysis, testing, OPEX or a combination of all of them) should be selected to ensure the cable penetration is environmentally qualified. If testing is selected, the EQ test programme should be designed to demonstrate that the cable penetration would maintain acceptable performance during its qualified life when subjected to the normal and accident service conditions. In addition, it should consider an appropriate test sequence.

An ageing programme for cable or electrical penetrations should contain the following inspection points: visual inspection, corrosion, cracking, isolation resistance measurement, material shrinking, embrittlement, etc.

The CADAK phase two contains primary the extension with the necessary fields in the database. During CADAK phase two the adding of data of electrical penetrations into the database was started.

7. Research and experimental focus areas of member countries

7.1. Introduction

Currently, the accelerated-aged cables in the laboratory and assumed the modern codes/standards are used as the basis for assessing the impacts of ageing on the physical properties of cables that are either environmentally qualified for DBAs or already being re-qualified for life extension. These modern codes/standards are the basis for cable qualification procedures. In order to have a reasonable assurance that age-related degradation mechanisms do not significantly affect the long-term safe and reliable operation of NPPs, the nuclear power industry and the regulators have recommended the development and implementation of a comprehensive and co-ordinated cable ageing management programme for all NPPs.

7.2. Canada

In 2012, the Canadian Nuclear Safety Commission (CNSC) has sponsored a research project, titled "Ageing Management of Cable in Nuclear Generating Stations" [9], which objective is to provide the background and technical basis supporting regulatory guidance, consistent with the requirements of CNSC regulatory document, REGDOC-2.6.3, "Ageing Management" [3], pertaining to the recommended core elements of a cable ageing management programme in Canadian nuclear power plants (NPPs).

Based on this study a number of recommendations were developed for Canadian regulatory guidance on the basis of the current international guidance and core program elements established consistent with USNRC regulatory guide RG1.218 [4]. As a result, the following 11 core elements were defined as essential to an effective cable ageing management programme:

- definition of scope of cable to be addressed by programme;
- develop and maintain a database of all cables to be monitored;
- characterise and monitor service environments;
- identify stressors and expected ageing mechanisms;
- select condition-monitoring techniques suitable to monitored cables;
- establish baseline condition of monitored cables;
- identify cable characteristics/ageing effects monitored by each CM technique;
- periodically perform condition-monitoring (CM) tests and inspections on cables;
- periodically review and incorporate plant and industry experience;
- periodically review, assess, and trend the condition of monitored cables;
- identify degraded conditions and define/take corrective actions.

Consequently, Canadian utilities or reactor operators have implemented cable condition-monitoring/surveillance/preservation programmes and cable ageing managements to assess, over time, the degradation of cable insulation.

Currently, CNSC has approved a research project, which evaluate properties of cable insulation materials removed from permanently shut down Gentilly-two nuclear power plant, by “Analysis of Degradation Mechanisms of Cable Insulation, I&C Equipment due to Ageing in a Decommissioned Nuclear Power Plant”[5], with the following objectives: To measure, record and analyse material properties of sample cable insulations from the permanently shut down nuclear reactor, at Gentilly-two NPP, to assess the degradation advancement on cables. The project will also include a comparison of the test data received from the real aged cables versus samples aged in a laboratory following practices upheld by modern codes and standards. Refer to Section 8.5 for the current status of this project.

This research is similar to another research project sponsored by CNSC in 1991 on the evaluation of insulation cable materials from nuclear power demonstration (NPD) Station, except the assumptions utilised as the basis of the existing cable qualification has not been covered in the study, since its purpose was to assess degradation of NPD cables and to determine the functional capability of naturally aged and further accelerated-aged cable samples under LOCA and post-LOCA conditions. With regard to the degradation of NPD nuclear generating station control and power cables after approximately 25 years of service, it was concluded that 1) the degradation of samples from the containment boiler room was minimal, caused mainly by thermal conditions rather than radiation; 2) although irradiation to 550 kGy (55 MRad), simulating normal operation and accident radiation levels, caused degradation, the cables could still function during accident and post-accident conditions; and 3)accelerated thermal ageing to simulate an additional ten years of service at 45 °C caused embrittlement of the PVC and 60% decrease in elongation of the Styrene Butadiene Rubber (SBR).

Furthermore, CNSC plans to participate in work activities with US NRC in a working group related to harvesting several electrical equipment/components, including cables. This will also lead to the development of a database for these materials.

The decommissioned NPPs provide an opportunity for the nuclear industry and the regulatory body to verify, validate and/or confirm the assumptions used as the basis of current qualification for cables. This might later evolve into improvements of the current qualification approach for cables important to safety within NPPs.

7.3. France

Research programme for new in-containment cables:

The ongoing research programme led by the Institute of Radioprotection and Nuclear Safety (IRSN) since 2012 is focused on “K1 qualified” cables of last generation, located in the containment. The cables of interest are power and I&C cables. The insulation and jacket materials of these halogen-free cables are mainly composed of EVA, EPDM and PE.

The radiolytic and/or thermal degradation of polymers are performed under accelerated ageing conditions. In the first phase of the programme, the ageing conditions are representative of the normal operating conditions in nuclear containment environment (50°C, 0.1 $Gy.h^{-1}$, 70% of Relative Humidity), simulating up to 80 years. An experimental design is implemented in order to study the behaviour of polymers according to different doses (up to 70 kGy) and dose rates (0.2 to 5 $kGy.h^{-1}$).

The polymers degradation is studied on different types of materials (complete cables, model materials) in order to appreciate the effect of the diffusion of the oxygen in the material (distinction in between thermo-oxidation and radio-oxidation). The model materials based on the same main formulation as the general insulation materials, will allow enhancing the understanding of the ageing mechanisms. A predictive model of the ageing of the insulation material will be finally established.

It is important to combine different approaches to characterise the degradation of polymers: mechanical tests (elongation at break, micro hardness) providing a macroscopic characterisation and physicochemical methods (OIT, OITP, FTIR, DMA) allowing assessing the evolutions of the chemical modifications (level of antioxidants, evolution of the polymers macromolecules structure...).

It has to be justified that degradation of insulation permits to ensure electrical performances of polymer cables for design basis event and during the first days of a severe accident. Mineral cables are generally used for in-containment instrumentation channels needed for longer period in case of a severe accident (with core melt).

Condition monitoring of in-containment cables

For 900 MW and 1 300 MW French NPP, important safety cables located in containment that are required in case of LOCA/MSLB, are EPR/CSPE cables.

From 2008 to 2012, environmental measurements have been performed in NPP to determine ambient conditions of cables in containment (temperature and dose rate). It has permitted to determine the stress level to which cables are submitted in normal operation and to choose samples to expertise.

Then degradation states of aged samples coming from plants have been determined through different methods (elongation at break, gel fraction, OIT, FTIR and NMR). Électricité de France (EDF) has decided to take samples (EPR/CSPE), whose portions have been submitted to more penalising environmental conditions (heating, radiation dose rates). Other portions permit to have characterisation at different dose rates and temperatures. Twenty and thirty years olds samples have been taken from plants.

These measurements will be used:

- to determine the degradation of insulation materials
- to confirm the ability of cables to withstand accidental conditions regarding past experimental studies and
- to improve the kinetics model and to verify its validity regarding the measurements performed.

This experimental phase will be performed for three years period (2014-2017) for 900MWe-series. Next step consists of performing accelerated ageing on these samples to determine the consumption of antioxidants after an additional ageing (for the next 10-20 years).

Condition monitoring of out-of-containment cables

From 2008 to 2012, environmental measurements have been performed on site to determine ambient conditions of cables in specific places out of containment (temperature and humidity). This concerns especially locals with steam circuits and high loaded power cables.

Focus is put on power cables, regarding temperature cycling and humidity issues.

EDF has decided to take samples, whose portions have been submitted to more penalising environmental conditions (heating of conductor, humidity). 30-years olds samples have been taken from plants. Next step consists of determining the degradation of insulation materials (physical, chemical and electrical characterisations).

Diagnostic methods

Currently, main interest is focused on:

- validating non-destructive methods used to localise degradation of the insulation materials on an anticipated way (for example, line impedance reflectrometry and tan delta),
- developing non-destructive methods used to determine degradation of connectors (increase of contact resistance, diminution of traction force needed to lose connection),
- improving tests modalities to limit measurements uncertainties and to increase reproducibility on micro sampling or thin layers.

7.4. Japan

Cable condition-monitoring technique

The new Nuclear Regulation Authority (NRA) has been evaluating Broadband Impedance Spectroscopy (BIS) technique for application to condition monitoring of electric cables used in NPPs.

Cable samples of Flame Retardant Ethylene Propylene Rubber (FR-EPR) insulated cable and Silicone Rubber (SIR) insulated cable, which are commonly used types of safety-related low-voltage cables, are aged by accelerated ageing to simulate the degradation by temperature and radiation expected in operating NPPs.

The cable samples are tested in laboratories using the BIS technique, and the obtained data are analysed to evaluate if the technique has enough detectability to judge proper operation of cables during and after the design basis accident. This research programme began in 2012 and continued until 2016. Some information on this project is provided in IAEA report in reference [14].

7.5. Slovak Republic

Since 2014, activities focused on the application of line impedance resonance analysis (LIRA) system into the ageing management programme and condition monitoring have started. Selected low voltage (LV) and medium-voltage (MV) cables in NPP are measured using both system and conventional time domain reflectometry (TDR) device and suitability of LIRA system for application in cable ageing management programme (AMP) is analysed.

Environmental condition monitoring

Since the 2015 environment monitoring focused on cables is carrying out in Mochovce NPP and Bohunice NPP to determine environment conditions (temperature, radiation dose, humidity) in selected areas within and outside containment. Data loggers, temperature labels and alanine dosimeters are used as technical devices for monitoring. The main purpose of monitoring is to get real information on conditions to which cables are exposed and consequently localise hot spots. Detection of adverse environments allows us to manage these environments and/or mitigate their impact on cable. Obtained real environment conditions can/will also be used for revaluation of cable qualified lifetime.

7.6. Spain

In 2003, the Spanish Regulatory Body (CSN) and the Spanish Electricity Industry Association (UNESA) initiated a joint research project (JRP) on the ageing of electrical cables at NPPs, made up of the following phases:

Phase one: PCI ES-13: "Surveillance of electrical cable ageing at nuclear power plants"

The main objective of this phase of the project carried out in 2004, was to define a "common basis action plan", applicable to all the Spanish plants for the performance of systematic cable ageing surveillance programmes. The aim was, for these programmes, to be aligned with the international state of the art in this area, and in particular with the recommendations and contents of the IAEA-TECDOC-1188, "Assessment and Management of Ageing of Major NPP Components important to Safety: In-Containment I&C cables".

An initial activity of this project was an in-depth review of the national and international literature (IAEA, NUREG, EPRI, Sandia reports, NRC documents, etc.) on cable ageing with a report being drawn up.

As a basic conclusion to this phase of the project, it was determined that the ageing surveillance techniques potentially appropriate for the types of cables in place at the Spanish plants were: measurement of the compression module (indenter method), thermogravimetric tests (TGA) and induced oxidation time and temperature tests (OIT, OITP).

Likewise, the following documents were drawn up for application at the different plants:

- UNESA document Nº ES13/IT-01-103: "National and International Research and Development Status Evaluation Report"
- UNESA document Nº ES13/IT-02-0903: "Guideline for Monitoring of the Status of Electrical Cables.".
- UNESA document Nº ES13/IT-03-0903: "Technical Procedure for the identification of Critical Environmental and Service Parameters".
- UNESA document Nº ES13/IT-04-0903: "Selection of Circuits and Definition of the Surveillance Programme".
- UNESA document ES13/IT-05-0903: "Technical Procedure for the Electrical Characterisation of Cables".
- UNESA document ES13/IT-06-0903: "Technical Procedure for the Mechanical Characterisation of Cables".

Phase two: PCI ES-24 "Application of Advanced Techniques for the Diagnosis of Electrical Cables at Nuclear Power Plants"

The basic objective of this phase of the project carried out over the period 2006-2009, consisted of determining, in a practical manner, the applicability of the ageing surveillance techniques identified in previous phase one, for monitoring of the status of the cables in place at the Spanish NPPs.

The project was performed by way of the following activities:

- Collecting of cable samples (new and naturally aged) representative of those installed at the Spanish plants.
- Thermal and radiation-induced ageing of these samples, for periods of 20, 40 and 60 years.
- Acquisition of values of elongation at break (EAB) and tensile strength (TS) of aged samples.
- Application of selected techniques (indenter method, TGA, OIT, OITP) to aged samples. Acquisition Validation and adjustment of results.
- Comparison of the results of the techniques applied to the corresponding values of EAB and TS, obtaining correlation factors between the test values and the degradation of the aged cables.

The following different cable insulation and sheath materials combinations were tested: EPR/CSPE, ETFE/CSPE, PVC/PE, XLPE/CSPE, EPR/AFUMEX, and AFUMEX/AFUMEX.

This phase of the project has concluded that, for most of the tested cables, the indenter modulus is the basic technique to be applied for assessing the cable condition. Indenter could be complemented, where necessary, with the OITM and OITP techniques. Acceptance criteria for each technique and type of cable were also determined. The TGA technique did not prove, in general, to be applicable to determined cable condition.

Phase three: PCI ES-27: "Tracking and Assessment of Electrical Cables Status at the Spanish Nuclear Power Plants".

This phase of the project began in 2014, and is currently being carried out by UNESA and the Spanish plants. The project is performed in response to the recommendations of CSN, to verify the validity of the cable environmental qualification processes, performed in accordance with IEEE-383-1974, as a result of the "uncertainties of these qualification processes", identified by recent international research programmes on cable ageing (IAEA, NRC, NEA, Japan-JNES) (see Section 5 of this report).

The main objective of this phase of the project is to obtain "condition indicators" (CI) for the cables, making it possible to effectively control their ageing status throughout the long-term operating (LTO) period.

In this respect, new qualification tests will be performed, limiting the effect of the aforementioned uncertainties, on a representative sample of the cables in place at the Spanish plants.

The tests will be performed on naturally aged (30 years) samples of cables taken from the plants, their ageing being completed to 40, 50 and 60 years by means of a sequence of accelerated ageing tests (thermal + radiation) with low acceleration factors and dose rates. Subsequently, the accident radiation test and finally, the LOCA and post-LOCA tests, will be applied.

During the process, samples aged to 40, 50 and 60 years will be extracted and different surveillance techniques (elongation at break, indenter, insulation resistance, polarisation index, etc.) will be applied to them, obtaining the corresponding CI values prior to and following LOCA. In this way, the "critical level of degradation" (CLI) of each cable will be determined. Ageing management of the cables, using the defined CLI, will be assessed throughout the long-term operating period.

The ageing test phase of the project was initiated in 2017. The completion of the project is scheduled for the year 2020.

7.7. Switzerland

In line with chapter 7.1, the Swiss regulator has recommended the development and implementation of a comprehensive and co-ordinated cable ageing management programme for all NPPs. This is realised within the overall frame of the general ageing management programme according to the Swiss law.

The basis for the ageing management of electrical components in the Swiss NPPs is a specific guideline. Hence, for all components classified 1E according to this guideline, type and manufacturer-specific fact sheets must be created. This includes electrical cables that are necessary for ensuring that safety functions are fulfilled. Each fact sheet comprises three parts: parts one and two have been jointly created for all Swiss NPPs, while part three is plant specific because of the use of different cable types.

Fact sheet part one contain all potential ageing mechanisms in respect of the relevant cable types obtained from the monitoring of the technical literature. Fact sheet part two contains possible diagnostics methods, with which the potential ageing mechanisms can be detected. Plant-specific fact sheet part three describes the applicable diagnostics methods that are used in the plant-specific maintenance programme and in the regulations for the periodic testing of cables. This closes the circle from ageing management to maintenance. The fact sheets are revised every five to ten years. New findings from science and technology, from internal and external operating experience are thus regularly incorporated in the ageing management and the maintenance programme. If plant changes affect fact sheet part three, then the fact sheets are adapted.

The ageing management programme for electrical cables was developed by the licensees of the Swiss NPPs. Plant-specific fact sheets for the class 1E electrical cables can be divided into the following groups:

Group one: Fact sheet for medium voltage power cables (⩾ 1kV)

Group two: Fact sheet low-voltage power cables (50V – 1kV)

Group three: Fact sheet for instrumentation cables (< 50V)

Group four: Fact sheet for special mineral insulated cables (MI cable)

The Swiss cable ageing programme is also in line with IAEAs relevant TecDocs. A detailed description according to the specification of WENRA about the cable ageing programme has recently been published on the ENSREG website for her topical peer review.

In Swiss NPPs, electrical cables laid in the plants are generally monitored by periodic visual inspections and diagnostic measurements to detect any ageing. Operational ageing management for cables is an extension of the originally performed qualification tests and is based on the monitoring of the change in the elongation at break of cable sample materials. In most of the Swiss NPPs, cable samples that have been stored in high stress test areas for cable pre-ageing, where there is a high radiation and thermal load, are monitored in respect of their ageing behaviour. One Swiss NPP takes part in a German joint programme (VGB) therefore. Also the cabling has been consistently replaced during plant modifications. So different cables had to be qualified for their use in specific environment conditions and there data to be documented in the fact sheets.

A lot of research activities has already been done in Switzerland during 1990 to 2003 on different cable types in different institutes e.g. Paul Scherrer Institute (PSI). At the moment the research activities are focused on the possibility of a comprehensive implementation of LIRA system into the ageing management programme (AMP) and condition monitoring. Selected MV and LV cables in different CH – NPP are measured using LIRA system and conventional TDR system. It is important to collect a lot of data from the cable and the environment condition on the whole cable way to get a representative amount of data. Afterwards the analysing will hopefully show the cable behaviour under different conditions. Also as a result we will obtain information about the suitability of LIRA system for possible future application in cable AMP.

Condition monitoring

Since more than five years in different NPP in Switzerland part of the cables are controlled with the LIRA and the TDR method according their actual condition. To implement such methods also for calculating and using for AMP the condition around the cables has to be measured and monitored continuously. Also you need the starting point and a representative amount of data to forecast a future ageing. When a forecast is possible, the method will be also compared with the Arrhenius model which is at the moment used for calculation of the life time calculation of cables. Cables measured in 2012 could now be re-analysed for the first time. Hence, for the first time it was possible to determine the change in cable parameters over five years.

General

For new cables so called finger print is done, to have an exact starting point after the cable installation and then the cables are measure in intervals (three to five years) to see a trend.

The LIRA method is useful for analysing the actual condition of the cable, but for the interpretation of the data you need a specialist. The specialists are the bottleneck for this method therefore some power plants try to build up their own knowledge. LIRA and the TDR measurements are going on in Switzerland. At this moment there are still not enough data available for a significant general output for installed cable.

According to the Swiss law, the ageing mechanisms applicable to the safety-relevant electrical cables must be identified, a check must be undertaken to determine whether the existing maintenance programme is suitable for promptly detecting ageing-induced damage and the findings from ageing management must be incorporated in the maintenance programme. For this purpose, manufacturer information and findings from operating experience from Swiss plants and other comparable plants, and from monitoring of the state of the art of science and technology must be considered.

In particular the accepted methods for prediction of potential ageing influences, the proof of accident-resistance, the cable type, the design specification, conditions of use, usage time forecast as well as the type, scope and findings of conducted tests are in particular to be recorded in the fact sheets for electrical cables. The periodic update of this information in the database of fact sheets leads to a common and currently synchronised information level, which aims to the same goal as outlined in chapter 1.2.

7.8. United States

Submerged cables

The US NRC is investigating the issue of submerged cables and the safety implications. Specifically, the suitability of condition-monitoring techniques is being evaluated to track degradation in a submerged environment. In addition, this project aims to develop an accelerated ageing plan for medium-voltage submerged cables. Following the development of a test plan, cables will be tested under these conditions and furthermore, condition-monitoring methods will be performed on submerged cables. Continued research on the degradation of submerged cables, specifically, the impact of combined stressors on ageing, end of life definition, and sensitivity of condition-monitoring tests, is expected to follow.

A report on submerged cables was published on March 2015 [8].

Assessment of condition-monitoring methods for electrical cables

There are a variety of environmental stressors in nuclear power plants (NPPs) that can influence the ageing of electrical cables, such as temperature, radiation, moisture/humidity, vibration, chemical spray, and mechanical stress. Exposure to these stressors over time can lead to degradation that may go undetected unless the ageing mechanisms are identified, and electrical, mechanical, or physical properties of the cable are monitored. Since some electrical cables never receive inspection, maintenance, condition-monitoring tests, or periodic replacement, the degraded conditions in electrical cables could go undetected over time, which could lead to abrupt failures and prevent various components from performing their safety function. Cable failures have resulted in plant transients and shutdowns, loss of safety redundancy, entries into limiting conditions for operation and challenges to plant operators.

The US NRC confirmed in its review of Generic Letter (GL) 2007-01, "Inaccessible or Underground Power Cable Failures that Disable Accident Mitigation Systems or Cause Plant Transients," that electrical cables are often overlooked or ignored in ageing analyses and condition-monitoring evaluations, since they are passive components that are generally considered to require no inspection and maintenance. However, electrical cables are very important safety components since they provide power to safety-related equipment, and are used for instrumentation and control of safety functions. GL 2007-01 showed that a significant number of failures occurred under normal service conditions within the service interval of 20-30 years, which is before the renewed licence period and before the end of the expected life span of the cables. The staff evaluation of the licensee responses to GL 2007-01 concluded that licensees should have a programme for using available diagnostic cable testing methods to assess cable condition. The staff finds that condition monitoring is essential for assessing the health and ageing degradation of electrical cables to ensure reliable operation of safety-related equipment, instruments, and controls during normal operations and design basis events.

This project will confirm the adequacy of the condition-monitoring methods, including: 1) mechanical condition indicators (e.g. elongation, indenter methods, recovery time); 2) dielectric condition indicators (e.g. insulation resistance, dielectric loss, time domain reflectometry, line resonance analysis, partial discharge); and 3) chemical indicators (e.g. oxidation time/temperature, Fourier-transform infrared spectroscopy).

Condition-monitoring tests should be conducted on a variety of cables, including various insulation types, low and medium voltage cables, power and instrumentation and control cables, naturally-aged cables, and new cables. Naturally-aged cable samples as well as new cables should be tested.

The first phase of the project will focus on assessing condition-monitoring techniques during normal operational ageing. Thus, cables should be subjected to normal operating conditions (temperature, radiation, humidity) in both mild and harsh environments to simulate up to 40 years. For better estimates of cable performance, simultaneous thermal and radioactive ageing should be performed to produce homogeneous degradation in the samples (i.e. appropriate acceleration factors under oxidative conditions). Depending on the insulation material and its sensitivity to acceleration factors, ageing of the samples could take as long as nine months or more based on the type of insulation and known characteristics.

The second phase will focus on cables subject to accident conditions and located in harsh environments. The intention is to focus on pressurised water reactors only but later plans will include testing cables under boiling water reactor accident conditions. These cables should be exposed to simulated accident (temperature, pressure, humidity, radiation, chemical/steam spray) conditions. The condition-monitoring techniques should be evaluated for the capability to predict proper operation of cables during and after the accident (post-accident period).

This project began in 2012 and it will continue until 2019. This report was published near the end of the second term of the project.

7.9. The International Generic Ageing Lessons Learned (IGALL) for Nuclear Power Plants.

The IAEA Safety Standards NS-G-2.12 [10] requires that ageing and potential age-related degradation are considered in order to ensure the capability of the SSC to perform the specified safety functions throughout its design life. Ageing in all conditions and plant states including a postulated initiating event shall be taken into account. Provision shall be made for monitoring, testing, maintenance, surveillance and inspections in order to assess ageing mechanisms predicted at the design stage and to identify unanticipated behaviour that may occur in service.

In order to assist its member states in dealing with the challenges associated with long-term operation (LTO) and ageing management (AM), the IAEA has published multiple reports and conducted multiple programmes (e.g. SALTO and IGALL). General guidance on methodologies and implementations of ageing management is provided by the Safety Standard on Ageing Management [10] and in the SALTO reports [11] and [12]. However these documents do not provide information on specific degradation mechanisms of SSCs or related mitigation-specific ageing management programmes (AMP).

To complement the existing guidance described above, the IAEA initiated in 2009 the extra-budgetary programme (EBP) on IGALL for nuclear power plants (NPPs) with the objective to provide a current technical basis and a current practical guidance on managing ageing of mechanical, electrical and I&C components and civil structures of nuclear power plants important to safety. Scope and frame of the IGALL programme was initially based on the US NRC Generic Ageing Lessons Learned (GALL) programme [13].

The first phase of the IGALL program was conducted from 2009 to 2013, the second phase was conducted from 2014-2015 and the third phase was finished at the end of 2017. The IAEA IGALL database contains ageing management review (AMR) tables, ageing management programmes (AMPs) and the time limited ageing analyses (TLAA). The information contained in the IGALL database is based on approaches developed and implemented in various types of reactors in participating member countries and it is updated during each phase of the programme.

The following ageing management programmes of IGALL are connected with issues of cables ageing, condition monitoring and qualification:

- AMP201_Insulation Materials for Electrical Cables and Connections not Subject to Environmental Qualification Requirements.
- AMP202 Insulation Materials for Electrical Cables and Connections not Subject to Environmental Qualification Requirements Used in Instrumentation Control Circuit.
- AMP203 Inaccessible Power Cables not Subject to Environmental Qualification Requirement.
- AMP206 Electrical Cable Connections not Subject to Environmental Qualification Requirement.
- AMP207 Environmental Qualification of Electrical and Instrumentation and Control Component.
- AMP209 Ongoing Qualification of Electrical and I&C Components Relevant to an Environmental Qualification.
- AMP210 Condition Monitoring of Electrical and I&C Cables Subject to Environmental Qualification Requirement.

The ageing management programmes (AMPs) collected in IGALL database describe the actions and procedures for manage and assess ageing effects and time limited ageing analyses (TLAAs) describe how analysis of critical components in each plant type and design are done for the defined target of plant life time.

IAEA IGALL programme have only a single TLAA for electrical and I&C components: TLAA201 Environmental Qualification of Electrical and I&C components. This TLAA addresses equipment re-analysis or ongoing qualification methods to establish an electrical and I&C equipment’s qualified life for the intended period of operation. In this TLAA accelerated thermal ageing estimated with the Arrhenius model is referenced. In order to limit known uncertainties during cable qualification, the application of low dose rate for accelerated ageing is suggested.

8. Actions in CADAK

8.1. Principal steps

It is recommended to partner with other international organisations to leverage resources and prevent duplication of testing. For example, IAEA has conducted research on the ageing and condition monitoring of low-voltage power and I&C cables – see IAEA-TECDOC-1825 [14]. Shared expertise and knowledge would be beneficial for both regulators and utilities to develop cable ageing management programmes. Attending relevant IAEA meetings and collaborating with cable experts from cable manufacturers, utilities, and regulators allows for the wide dispersion of operating experience and research developments. For example, results from the IAEA research, including cable technical data, ageing characteristics, and condition-monitoring results, was planned to add to the CADAK database for information purposes and for those countries investigating cable research programmes.

Furthermore, EPRI (Electric Power Research Institute), UJV Rež (Institute of Nuclear Research), and Électricité de France (EDF) held an International Nuclear Plant Electrical Cable Ageing Management Symposium in September 2013. This symposium was attended by cable manufacturers, researchers, utilities, academia, and regulatory agencies. Topics of discussion included medium voltage cable, cable ageing management, manufacturing insights, condition monitoring, and acceptance criteria. CADAK was planned to be a resource for papers and presentations from such conferences as well as a collection on history records of cable testing, knowledge and expertise.

The goal of CADAK was to present the international research projects and cable conferences in order to collect information that would enhance the database and also, to become the premier database for electrical cable knowledge, expertise, and history.

8.2. Assessment of cable material of the decommissioned nuclear power plants

Cables are of key importance to the safe and reliable operation of nuclear power plants (NPPs). This is because of their widespread use as a connection medium with many systems important to safety within NPPs. Further, given that most of the existing NPPs are reaching or even exceeding their nominal design life, ageing impacts on cables is an important phenomenon for many of these systems.

Some plants have adopted a prospect to extend their operating life to additional 40 or more years beyond the original intended design life which also includes cables. It will therefore be appropriate to ensure that sufficient safety margin is still available for environmentally qualified cables and other cables important to safety. This can be done by studying samples of accelerated-aged cable in a laboratory and as assumed in modern codes/standards and comparing these results with actual aged cables available in the NPPs that have been recently shut down awaiting decommissioning or in the decommissioned NPPs.

The removal of cable insulation material from recently and permanently shut down and/or decommissioned NPPs is important since it will provide useful experimental data for the following purposes:

- examining properties of naturally-aged cable insulation material versus those of accelerated-aged cable insulation material in laboratory as per modern codes/standards;
- evaluating the impact of synergistic effects for different degradation mechanisms on removed and aged cable insulation material;
- determining the validity of laboratory test results of accelerated-aged cable insulation material;
- verifying whether the removal of unnecessary conservatism is warranted while maintaining sufficient safety margins.

There are currently underway various research projects in the nuclear industry to assess cable insulation material removed from decommissioned NPPs. These projects will address the above four items, including identification of key operational variables related to cable ageing, optimisation of inspection and maintenance schedules, as well as support in modelling activities, surveillance, and testing criteria [1].

Furthermore, it is worthwhile to note that a number of insights come from the NEA SCAP Project in years 2006-2010 [2]. These insights are: Selection of appropriate activation energy, impact of simultaneous thermal and irradiation ageing, dose rate effects, manufacturing tolerance and oxygen-starved chambers for LOCA tests.

With permanently shut down or/and decommissioned NPPs, the nuclear industry and the regulators have an opportunity to verify, validate and/or confirm the assumptions used as the basis of current EQ for cables. Thus, the assessment of results on these cables (taking into account the above four items) might improve the current EQ approach for qualifying cables important to safety within NPPs.

If these assumptions above are validated, then the cable samples removed from decommissioning NPPs should be used to verify whether these cables are qualified for additional qualified life beyond 40 years. This could be a good topic for future research or discussion in international decommissioning programmes.

8.3. Ensuring the long-term operation

8.3.1. Qualification for operation time over 40 years

There is not so much operating experience of cables for NPPs beyond 40 years of life in the world. In some NPP's the aged cables in critical positions are changed with significant programmes and the modifications are done in order to provide milder environment conditions (e.g. lower temperature and less radiation doses) for these cables. In many other plants no significant ageing of the selected cable materials are not recognised during long-term operation.

Many plants are reaching the end of the originally defined operation time 30 or 40 years of cables. However, there is not typically a significant difference between the ageing mechanisms of cables present after 40 years compared to those present after 60 years [13]. Most age-related degradation mechanisms occur slowly and, if unmitigated, and do have the potential to gradually worsen over time and there is not typically a distinction between the mechanisms present at 40 years compared to those present at 60 years. Therefore, collected operating experiences and test results during 40 years operation can be extrapolated into 60 years, when the safety margins are adequate. In most NPP's the continuous monitoring and more comprehensive analysis by owner, reviewed by regulator in periodic safety review (PSR) every ten years is done for ensuring the safety.

8.3.2. Qualification for operation time over 60 years

As said above the extended operational licensed time frame over 40 years has been based on renewing the ageing analysis of mechanical and electrical parts including cables and their EQ simulation and testing results for new 50 or 60 year life time target. In many countries the approval means that the analysis and the test results for the new life time are continuously confirmed with operating experiences during operation and comprehensively reviewed during PSR process.

In the USA nuclear industry has recently announced that a subsequent licensing renewal application from 60 to 80 years is under consideration. Similar life time extension plans are under consideration in many other countries. Demonstrating adequate cable performance and ageing management in normal operation and post-accident services for the periods over 60 years will be a demanding challenge. In considering operation more than 60 years the method to extrapolate qualified life is more questionable, when existing margins are eroded and the uncertainties inherent in the original sequential accelerated ageing programmes become more demanding. Therefore, it looks obvious that approval of life time over 60 years or even longer needs new test results and research as well as more operation experiences and their analyses for recognising the critical subjects and targets for additional inspections, assessments and preventive maintenance.

8.4. Forms of test data

Laboratories performing cable testing (used by regulators or utilities)

Performing cable testing requires specialised equipment and resources in the laboratory. Laboratories have particular equipment to perform chemical, electrical and mechanical condition-monitoring tests. Some laboratories may concentrate on a particular area and utilities and research organisations should take advantage of the expertise. In IAEA-TECDOC-1825 [14] comparisons of various testing technics and test results of certain laboratories are presented and compared. Based on the reference [14] the EAB, OIT and OITP technics are useful and reliable to all low-voltage cable materials for measuring the ageing effects.

Furthermore, cable ageing requires facilities that can execute thermal ageing, radiation ageing, and perhaps, simultaneous thermal and radiation ageing. These facilities that can perform simultaneous thermal and radiation ageing are limited in number and sharing the identity of these facilities would allow continued research. Many research organisations do not have their own facilities for radiation ageing and it may be difficult to achieve certain dose rates or total dose at small facilities. Thus, sharing the facilities would allow for more efficient research and for cable experts to collaborate on research.

8.5. Recent tests in Canada

The harvesting of systems, structures and components (SSCs) from decommissioned or decommissioning nuclear NPPs becomes so important nowadays as explained in Section 8.2 and it is beneficial on making decision for the technical feasibility of LTO of NPPs.

However, there are several challenges associated with harvesting materials from these plants. These challenges are: the removal of material samples from a decommissioned NPP is neither a compliance nor licensing activity for utilities or operators, high cost related to carry out research activity on these materials, inaccessibility or contamination of materials to be removed, accessibility of analysis and testing records (e.g. data, samples, etc.), shipping or transportation concerns (nuclear waste or SSCs), etc.

For harvesting of cables, it should be noted that material properties of cables aged in real time and real operating conditions can be significantly different from the properties received by studying samples aged in laboratory and assumed in current codes and standards.

Thus, Canada currently has a harvesting project on the analysis of degradation mechanisms of cables from Gentilly-two (G-2) NPP. G-2 is a CANDU-6 (675 MW(e)) nuclear reactor which was permanently shut down in 2012 after 29 years of service. The main objective of the cable harvesting project from G-2 is to better understand and assess the ageing phenomena with real aged cables resulting from thermal and radiation ageing and validate environmental qualification (EQ) process of cables.

The current status of this project is as follows: 1) the review of environmental conditions and the selection of cables to be harvested from G-2 NPP were already completed by the Canadian National Laboratory (CNL); 2) CNSC staff has recently witness the removal of cable samples from G-2 NPP; 3) the cable samples removal will be completed in early April 2017; and 4) preliminary testing results are targeted for September 2017. A variety of both destructive and non-destructive techniques (e.g. dissipation factor, indenter, EAB, etc.) will be used to assess current cable degradation at G-2 due to thermal and radiation ageing.

Figure 8.1. Pictures of Removal Cable Samples from Gentilly-2 Nuclear Power Plant

The current status of this project is as follows:

1) Preliminary results are currently available and are included in this report;

2) Final results will be available by the end of April 2018. A variety of both destructive and non-destructive techniques (e.g. dissipation factor, indenter, EAB, etc.) is used to assess current cable degradation at G-2 due to thermal and radiation ageing.

The preliminary analysis results are the following:

For samples removed from Room #403, the tan delta ranges from 5.17% (AL22A) to 5.90% (AL16A & CJ67A). The lower value is related to the reference tan delta for unaged PVC33A (5.23%), whereas the upper value of 5.90% is associated with reference laboratory tan delta measured for PVC33A after about 40 days of thermal ageing at 110˚C. Based on the PVC33A graph shown in Figure 8.3, the conservative end-of-service-life point of 50% relative EAB (i.e. 214/2 =107%) would be reached after 200 days at 110˚C. At that point tan delta would increase to 7.5% for PVC33A. Therefore, based on the tan delta results of all retrieved PVC33A samples, the expected remaining life is the equivalent of at least 160 days at 110˚C. Using an activation energy of Ea = 1.02 eV, 160 days at 110˚C corresponds to well over 100 years at 45˚C. This result is in agreement with the EAB results previously analysed for the PVC33A samples retrieved from Room #R403. The analysis based on EAB results showed that the condition of the PVC33A insulation samples removed from Room #R403 was similar to the condition of unaged samples [5].

For samples removed from Room #R001, the analysis indicated that the cable Sample #QA61A is showing signs of significant degradation for the PVC jacket and to a lesser degree for the XLPE insulation based on EAB results. This degradation is likely the result of significant exposure to radiation in a room where fuel bundles were being transferred. For the retrieved cable samples there was a broad variation in degradation (as per EAB results) whether measurements were taken close to or away from a crack that was observed on the cable jacket. This trend is confirmed by the electrical dissipation factor results. Tan delta measured away from the crack was 0.85%. However, at the insulation location corresponding to the crack on the jacket, tan delta for Sample #QA61A increased to 1.06% [5].

The insulation material of the cable Sample # BN18 removed from Room #R003 was PVC91. The cumulated average temperature in Room #R003 was 29˚C, which is relatively low. For PVC91, the activation energy used as part of the cable EQ process (as found in the EQ assessment report) was Ea = 1.23 eV. Based on this assumed activation energy and using reference EAB data, 29 years at 29˚C is equivalent to half a day at 110˚C. Therefore tan delta for the retrieved BN18R sample should be almost identical to tan delta for the unaged reference PVC91 sample (i.e. 4.21 %). The measured tan delta for Cable Sample BN18R was 4.39%, slightly up from the unaged reference value. A tan delta value of 4.39% corresponds to about 18.5 days of thermal ageing at 110˚C according to the reference PVC91 graph shown in Figure 8.2. Therefore, there is slightly more damage than would have been expected assuming an activation energy of Ea = 1.23 eV. This result is in good agreement with the analysis conducted based on EAB measured for Sample # BN18R [5].

Figure 8.2. Reference EAB Results for Thermally Aged PVC 33A, PVC 36A & PVC 91 [5]

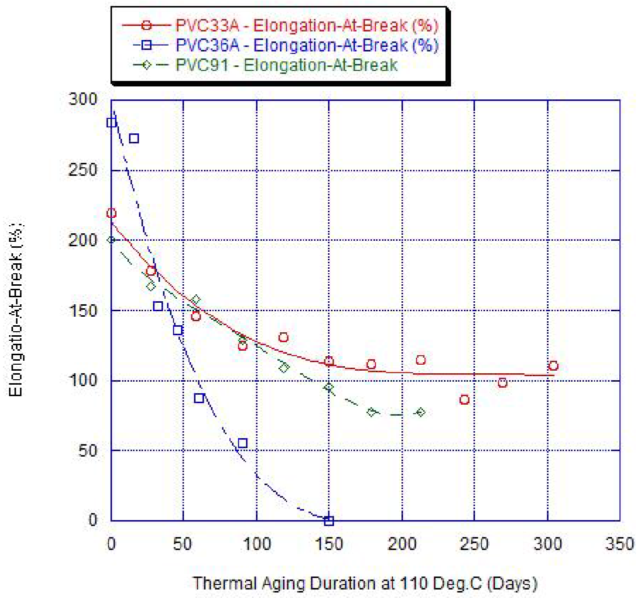
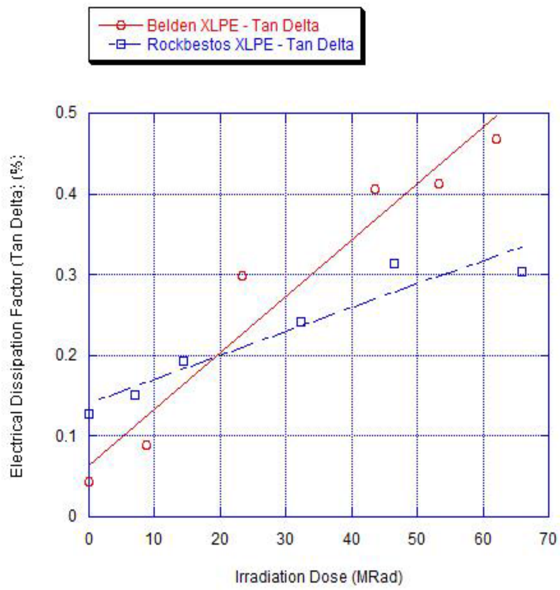


Figure 8.3. Reference Tan Delta Results for Irradiated Belden XLPE and Rockbestos XLPE Insulation



The goal of the project is to retrieve 92 samples from 47 different cables currently installed in the Gentilly-2 reactor building but the following tables (Table 8.1 and Table 8.2 only covers a limit number of these cable samples.

Table 8.1. Extracted Rows from the Cable Sample Characteristics (CNL)

Cable ID#	EQ Cable (yes/no)	Cable is safety significant? For non-EQ cables only	Cable Description (Type, Voltage, Total Length Installed)	Cable Start Location (Room #, Room Description, Elevation, NT Group #: Average Service Temperatures, NR Group #: Average Service Dose Rate)	Cable End Location (Room #, Room Description, Elevation, NT Group #: Average Service Temperatures, NR Group #: Average Service Dose Rate)	Equipment Involved	Insulation Material	Jacket Material	NIR Group ID# for Insulation Material	G2 EQ Dossier #	Location of Cable Tray (CT#) or Cable Electrical Conduits for aged cables section	Location of cable section to be retrieved as unaged (or mildly aged) reference sample	List of locations to retrieve samples from (including Room #, Tray # and Conduit #)
AL16	yes		Twisted Pair, 300V #16 NU,29579 m	R107, F/M Room (South), 23'-6", NT#5: 45-50°C, NR#1: 3.3 rad/h neutron + 23 rad/h gamma	R501, Steam Generator Floor, 80'-9", NT#3, 35-40°C, NR#2: 0.04 rad/h neutron + 0.4 rad/h gamma	63332-SV47#1, SV48#1,ZS47#1,ZS48#1	PVC	PVC	PVC33A	G2-Q-EQ-57110-007-1	R107 JB & Tray		One sample in R009 at tray riser #1000 = Ref = AL16R; One sample in R107 at 60800-JB1486 or in Trays #1135 or1134 = AL16A
AL22	yes		Twisted Pair, 300V #16 NU,42717 m	R107, F/M Room (South), 23'-6", NT#5: 45-50°C, NR#1: 3.3 rad/h neutron + 23 rad/h gamma	R305, Coolant System. (South), NT#1: 25-30°C, NR#2: 0.04 rad/h neutron + 0.4 rad/h gamma	63432-PT3K	PVC	PVC	PVC33A	G2-Q-EQ-57110-007-1	T=C R107, tray riser R005 for ref	Tray Riser in R005 + good ref in R305	One sample in R305 at 63432-PL1202 or in R009 at tray riser #1000 = Ref = AL22R; One sample in R107 in Tray #1134 or at 63432-JB1489 = AL22A
CJ67	yes		Twisted Pair, 300V #16 NU,73080 m	R405, Primary Coolant System, NT#1 : 25-30°C, NR#2 : 0.04 rad/h neutron + 0.4 rad/h gamma,	R403, D2O Supply Pumps, 64'-6 », NT#6 : 50-55°C, NR#2 : 0.04 rad/h neutron + 0.4 rad/h gamma,	63331-LCV12	PVC	PVC	PVC33A	G2-Q-EQ-57110-007-1	C&T R403,	C&T R405 for a PVC33A ref	One sample in R405 at 63331-LCV-12 = Ref = CJ67R; One sample in R403 at 60800-JB-3485 = CJ67A
BN18	yes		Twisted Pair, 300V #16 NU,25440 m	R003, Access Area, 3'-6", NT#1: 25-30°C , NR#3: 0.0003 rad/h neutron + 0.015 rad/h gamma,	R401, Zonal BL Settings , NT#2: 30-35°C, NR#3: 0.0003 rad/h neutron + 0.015 rad/h gamma)	63333-LT14B	PVC	PVC	PVC91	G2-Q-EQ-57110-014-0	Tray and Conduits REF	R003	One sample in R003 at 60800-JB2014 = Ref for PVC 91 which has a spectrum similar to PVC 101 and PVC 15 = BN18R
QA61													
QA61	no		3 cond #6 AWG, 600V	T403, Electric Equipment Room, 48'-0 », NT7 : 40°C	R001, NR4	3532-PM2	XLPE	PVC			C In R001, Ref in R006 and R007, release date 1983	R006 and R007	One sample in R006 or R007 in Tray RWY#4011 = Ref = QA61R.; One sample in R001 at 3532-PM2 = QA61A

Table 8.2. Results of Tensile, Electrical Dissipation Factor and Indentation Tests (CNL)

Cable ID#	Cable Sample Designation	Room #	Jacket and Insulation Material	Cumulated Average Temperature (˚C)	Cumulated Irradiation Dose (MRad)	EAB (%)		Tan Delta (%)	Indentation Tests	
						Median	Std. Dev.		Indenter Modulus (N/mm)	Recovery Time (s)
AL16	AL16R Jacket	R501	PVC	36.0	< 4.0x10-3	258	23	N/A	tbd	tbd
	AL16A Jacket	R107	PVC	tbd	tbd	284	22	N/A	tbd	tbd
	AL16R Insulation	R501	PVC33A	36.0	tbd	232	8	6.20	tbd	tbd
	AL16A Insulation	R107	PVC33A	tbd	tbd	218	18	5.90	tbd	tbd
AL22	AL22R Jacket	R305	PVC	25.9	3.7x10-3	259	35	N/A	tbd	tbd
	AL22A Jacket	R107	PVC	tbd	tbd	260	38	N/A	tbd	tbd
	AL22R Insulation	R305	PVC33A	25.9	3.7x10-3	240	4	5.35	tbd	tbd
	AL22A Insulation	R107	PVC33A	tbd	tbd	222	29	5.17	tbd	tbd
CJ67	CJ67R Jacket	R405	PVC	25.9	11.7x10-3	263	16	N/A	tbd	tbd
	CJ67A Jacket	R403	PVC	45.0	4.3x10-3	242	27	N/A	tbd	tbd
	CJ67R Insulation	R405	PVC33A	25.9	11.7x10-3	225	8	5.29	tbd	tbd
	CJ67A Insulation	R403	PVC33A	45.0	4.3x10-3	216	7	5.90	tbd	tbd
BN18	BN18R	R003	PVC	29.0	30.0x10-6	291	15	N/A	tbd	tbd
	BN18R	R003	PVC91	29.0	30.0x10-6	176	10	4.39	tbd	tbd
QA61	QA61R Jacket	T403	PVC	26.4	0.0	390	15	N/A	tbd	tbd
	QA61A Jacket	R001	PVC	30.0	tbd	187/84	69/8	N/A	tbd	tbd
	QA61R Insulation	T403	XLPE	26.4	0.0	486	54	0.93	tbd	tbd
	QA61A Insulation	R001	XLPE	30.5	tbd	296	140	0.85/1.06	tbd	tbd

9. Cable data analysis

The CADAK database includes 1 350 data sets from different countries with various technical specifications. Large part of this data originated to SCAP project is from non-member countries of CADAK and the detail information of the previous members are no more available. There is also large variation of cable types and insulation materials in the database. Differences in plant designs, in suppliers, in environmental conditions, in storage times, etc. have influence on the lifetimes of cables.

Based on these limitations the comprehensive analysis to the cable data in CADAK database has not been possible to be elaborated to this report.

10. Conclusions and recommendations

The Cable Ageing Data and Knowledge (CADAK) Project is the continuation of the cable ageing part of the NEA Stress Corrosion Cracking (SCC) and Cable Ageing Project" (SCAP). SCAP was formally launched in June 2006 and officially closed with an international workshop held in Tokyo in May 2010. The results of SCAP are in reference [2]. Following the completion of the SCAP project, its SCC working group participants were interested in some form of continuation and a new project was formed in 2011 by combining OPDE and the cable ageing part of SCAP into the CADAK.

During the first term of CADAK an operational web-based database and a web-based, knowledge-based (KB) structure on SCAP were used. The type of information collected includes regulations/codes and standards, and relevant documents on national activities in the areas of inspection/monitoring/qualification, repair/replacement of cables as well as on safety assessments and national R&D. The KB is intended to provide a source of systematically organised information for the project members.

Another objective in the first term of the CADAK was to define methods for collecting national information and documents into the database was successfully performed in some member countries, which also started the collection work. However, not all member countries started the use of the database and knowledge base during the first term of the CADAK. After the first term it was evident that the CADAK could be successful if up-to-date information is continuously added, and this information would greatly benefit utilities and regulators in understanding cables. In addition, for developing ageing management programmes, the CADAK should house current information and operating experience on condition-monitoring tests and acceptance criteria.

For the second term, the CADAK project defined goals for analysis of cable data; however, there are large variations of cable types and insulation materials in the database and differences in plant designs, in cable suppliers, in environmental conditions, in storage times, etc. that have an influence on the lifetimes of cables. Based on these limitations, a comprehensive analysis of cable data in CADAK database was not possible.

The following recommendations are defined for future work in the area of cable ageing:

- In future, the key objectives of work with cable ageing will be to encourage all countries to support the multilateral exchange of test data and operating experience of cables. If additional experimental studies allow the identification of ageing phenomena (generic issues) or improvement of associated kinetics and influence criteria, it should be published.
- It is recommended that all international working parties in the field of cable ageing exchange information with other international organisations (e.g. IAEA) to prevent duplication of research efforts.
- The information obtained from the decommissioned nuclear power plants (NPPs) should be used to verify, validate and/or confirm the assumptions used in the

current qualification for cables that are important to safety. Projects to collect cable samples removed from decommissioned NPPs should be used to verify whether these cables are qualified for additional qualified life beyond 40 years or even beyond 60 years. This could be a good topic for future research or discussion in international decommissioning programmes.

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12. Appendix 1 CADAK Database and knowledge base

CADAK Database Management

Following a login and verification process via the CADAK web-interface (http://cadak.hrp.no/cadak), data entry, data modifications and data retrieval is managed via menus, links, input tables (sheets) and roll-down menus.

Database Data Entry and Modification

A database entry requires a certain number of mandatory items to properly identify each data record. The number of such mandatory fields varies among the ten different database parts. In addition, for each of the ten parts, follows a certain number of required and optional items. Figure 1 and Figure 2 show examples of input tables for initiating (mandatory fields) and modifying a database record.

Figure 1: Mandatory fields for a new database record (Part 1)

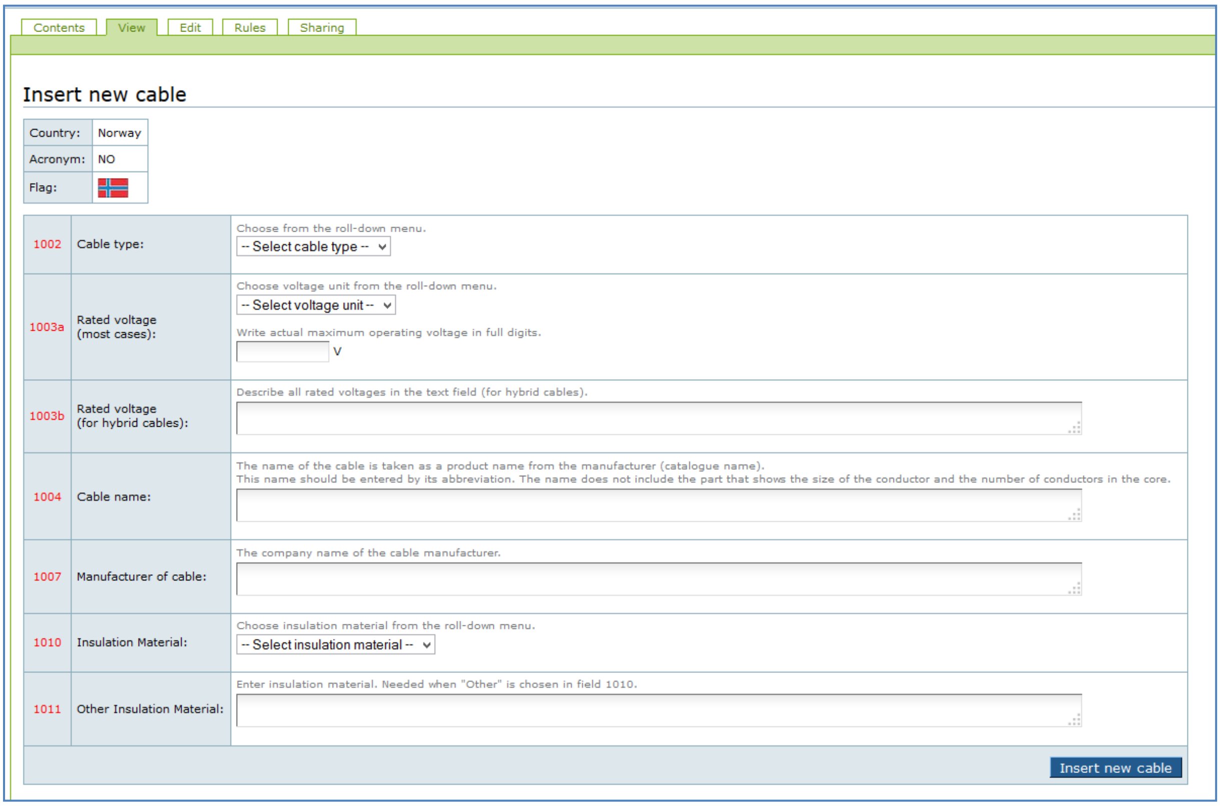
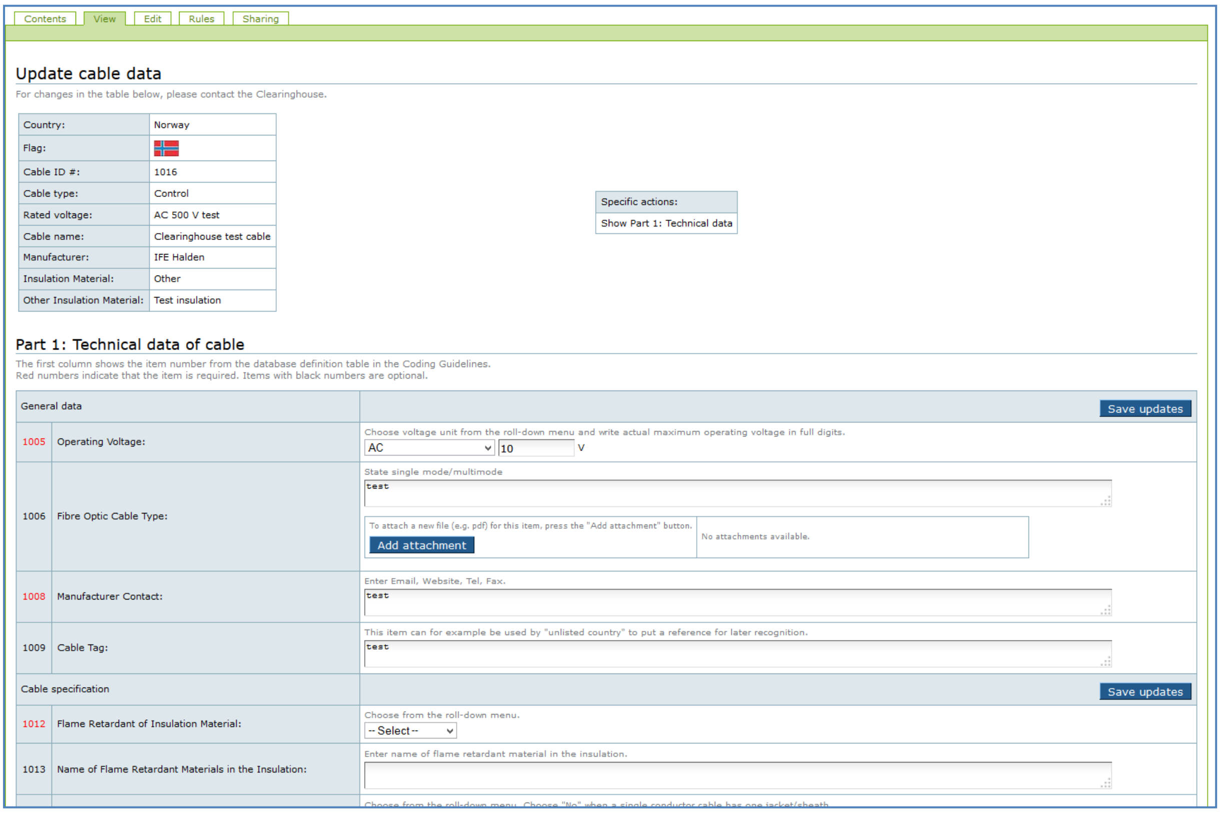


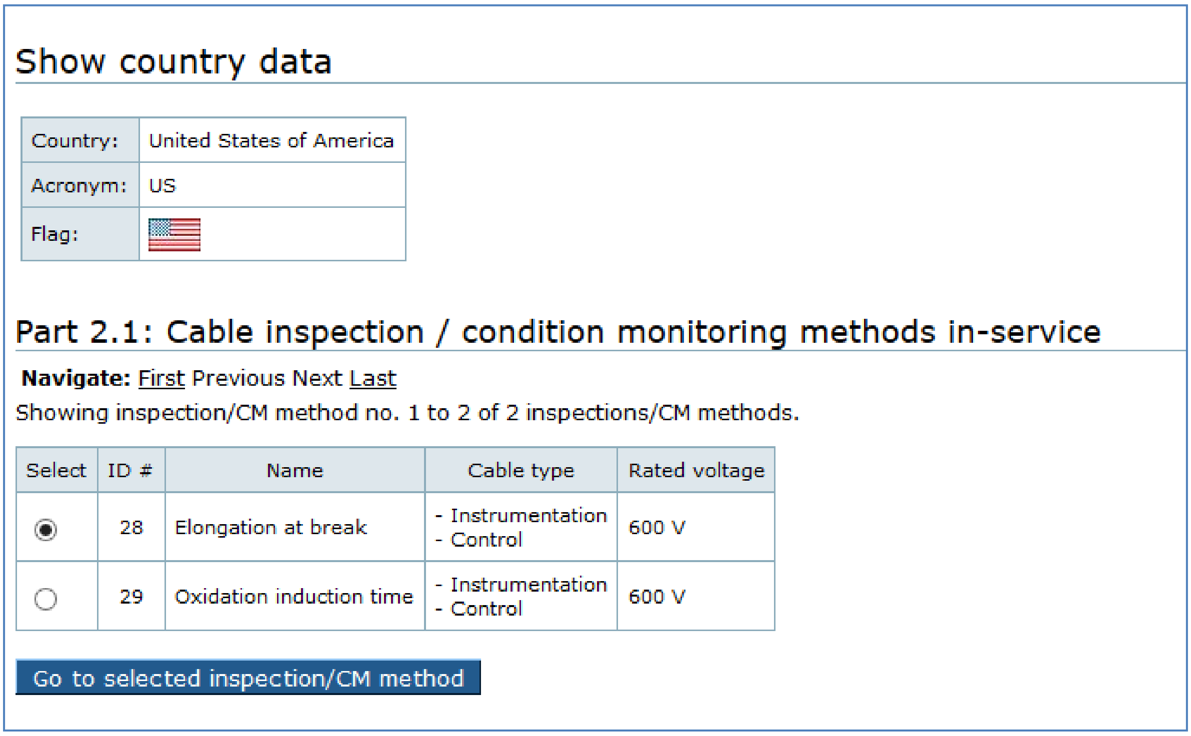
Figure 2: First section of a sheet for updating required/optional items for a new/existing database record (Part 1)



Database Data Retrieval

Data records can be retrieved either by selecting from a record menu (see Figure 3, or by utilising the search tool. Figure 4 shows an example of a retrieved data record in "view" mode.

Figure 3: Example of database record selection menu (Part 2.1)



Show country data

Country:	United States of America
Acronym:	US
Flag:	

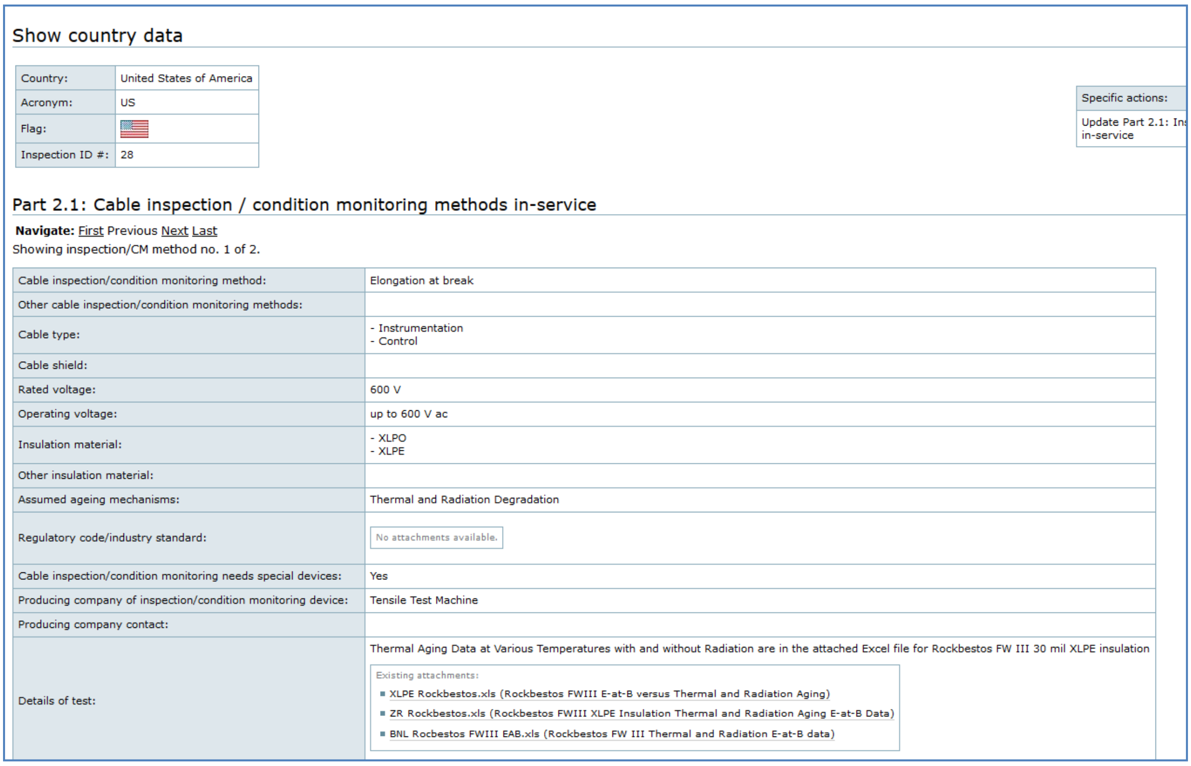
Part 2.1: Cable inspection / condition monitoring methods in-service

Navigate: First Previous Next Last
Showing inspection/CM method no. 1 to 2 of 2 inspections/CM methods.

Select	ID #	Name	Cable type	Rated voltage
◉	28	Elongation at break	- Instrumentation - Control	600 V
○	29	Oxidation induction time	- Instrumentation - Control	600 V

Go to selected inspection/CM method

Figure 4: Example of retrieved record data in "view" mode (Part 2.1)



Show country data

Country:	United States of America
Acronym:	US
Flag:	
Inspection ID #:	28

Specific actions:
Update Part 2.1: In
in-service

Part 2.1: Cable inspection / condition monitoring methods in-service

Navigate: First Previous Next Last
Showing inspection/CM method no. 1 of 2.

Cable inspection/condition monitoring method:	Elongation at break
Other cable inspection/condition monitoring methods:	
Cable type:	- Instrumentation - Control
Cable shield:	
Rated voltage:	600 V
Operating voltage:	up to 600 V ac
Insulation material:	- XLPO - XLPE
Other insulation material:	
Assumed ageing mechanisms:	Thermal and Radiation Degradation
Regulatory code/industry standard:	No attachments available.
Cable inspection/condition monitoring needs special devices:	Yes
Producing company of inspection/condition monitoring device:	Tensile Test Machine
Producing company contact:	
Details of test:	Thermal Aging Data at Various Temperatures with and without Radiation are in the attached Excel file for Rockbestos FW III 30 mil XLPE insulation Existing attachments: ▪ XLPE Rockbestos.xls (Rockbestos FWIII E-at-B versus Thermal and Radiation Aging) ▪ ZR Rockbestos.xls (Rockbestos FWIII XLPE Insulation Thermal and Radiation Aging E-at-B Data) ▪ BNL Rocbestos FWIII EAB.xls (Rockbestos FW III Thermal and Radiation E-at-B data)

Database Lifecycle

Cable data will go through different lifecycle stages while being stored in the CADAK Cable Ageing Database. During these lifecycle stages, different users will have different access to the data.

User Categories

The following user categories are defined for the Cable Ageing Database:

Table 1: User categories for the CADAK Cable Ageing Database

User category	Description
Operator	An industry representative or representative from a research facility or alike that has collected cable data and inputs the data to the database.
National representative	Main contact person for CADAK project in his/her country. Responsible/supervisor for all operators in his/her country. Provides data to the database either by having operators to contribute it, or by entering himself/herself.
Project representative	CADAK Secretariat, CADAK Consultant.
Administrator	The persons working at the Operating Agent.

Lifecycle Stages

Table 2 shows the lifecycle stages that are defined for the Cable Ageing Database

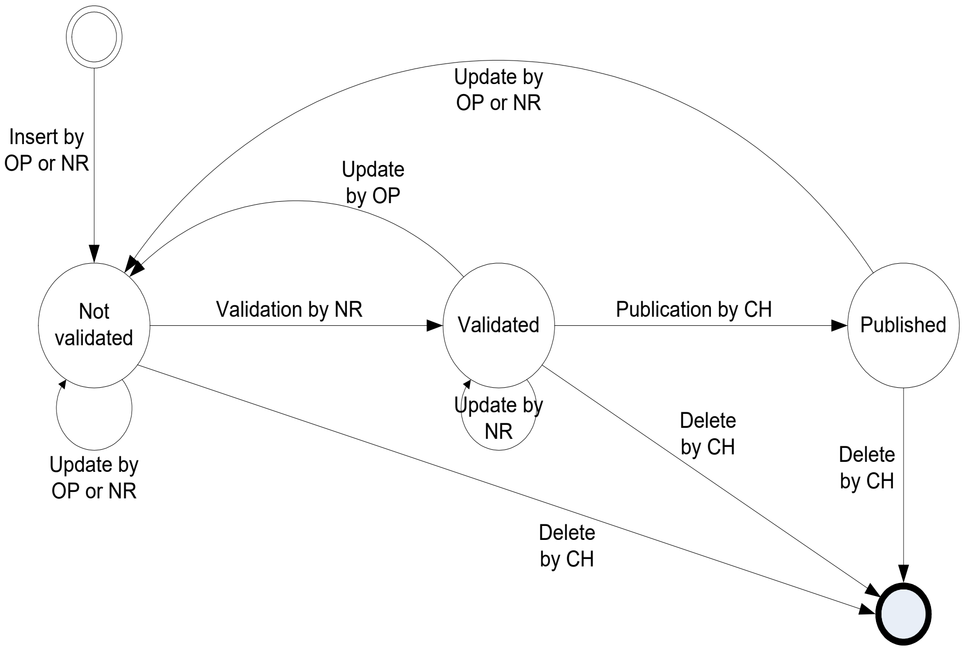
Table 2: Lifecycle stages for the SCAP Cable Ageing Database

Lifecycle stage	Description	Comment
Not Validated	The data is inserted by an Operator (or National Representative), but not yet validated by the National Representative	This means: The data may be under insertion, i.e. the Operator (or National Representative) is still working/inserting. Or the data is readily inserted, but not validated by the National Representative yet, i.e. the National Representative has not checked the validity of the data submitted by the Operator (or National Representative).
Validated	The data is validated by the National Representative, but not yet published by the Operating Agent.	This means: The National Representative has validated the data entered by the Operator (or National Representative), and has informed the Operating Agent that this data can be published.
Published	The data is published.	This means: The Operating Agent has verified and published the data in the database.

Lifecycle

Annex Figure 5 shows a state diagram explaining the lifecycle of an entry in the Cable Ageing Database.

Figure 5. Lifecycle of an entry in the Cable Ageing Database



Entries in parts 2.2, 2.3, 3, 6 and 7 of the database refer to cables defined in part one of the database. As a consequence, creation of entries in parts 2.2, 2.3, 3, 6 and 7 of the database require the existence of at least one entry for that country in part one (i.e. existence of at least one cable defined by that country). Deletion of an entry in part one of the database (i.e. deletion of a cable) requires that all data in parts 2.2, 2.3, 3, 6 and 7 of the database referring to that cable has been deleted.

Deletion of any data can be requested by all users. The National Representative who is responsible for the data shall be consulted before deletion. Only the Operating Agent has the possibility to delete data.

Data Access

Data Access Dependent on Lifecycle

Table 3 shows the access rights of different users to the data contained in the database, depending on the lifecycle.

Table 3: Data access depending on lifecycle

Lifecycle stage	Reading access	Writing access
Not Validated	The Operator providing the data and his/her National Representative; Operating Agent	The Operator providing the data and his/her National Representative; Operating Agent
Validated	The Operator providing the data and his/her National Representative; Operating Agent	The Operator providing the data and his/her National Representative; Operating Agent
Published	All users	Operating Agent

The Cable Ageing Working Group has decided that the database will be kept "open access" within the member countries, to solicit maximum participation from the industry. The open access policy was approved by the SCAP Management Board in June 2008 and later confirmed by the CADAK Working group. Open access means that all users have reading access at lifecycle "published".

User Configuration

Different access rights will be configured for different users of the database.

Table 4: Overview over users' access rights

User	Group	Reading access	Writing access
Operator	Country	All data entries	Data entries provided by this operator.
National representative	Country	All data entries	Data entries provided by this country.
Project representative	Project	All data entries	All data entries
Operating Agent	Administrator	All data entries	All data entries

Handling of Change Requests

It is possible that a member of the Cable Ageing Working Group, the Operating Agent or other involved project members want to introduce changes to the Cable Ageing Database, after the first release.

Changes in Roll-Down Menus

Adding a New Choice to a Roll-Down Menu

New choices in roll-down menus can be added according to the following procedure.

1. A CADAK Cable Ageing project member initiates adding a new choice in a roll-down menu by sending a request (e.g. by e-mail) to the Operating Agent.

The Operating Agent decides if this request is considered a minor one (e.g. a project member wants to add a new NPP in the list of NPPs) or a major one (e.g. adding a new cable type). If minor change, go to step three, if major change, go to step four.

The Operating Agent implements the requested addition to the roll-down menu and informs all involved partners.

The Operating Agent notes the request and takes it to the next Working Group meeting, where it is discussed and decided.

Adding a New Choice to a Roll-Down Menu where Choice "Others" is the Same Several Times

For some roll-down menus, a choice "Others" is defined, with a text field following, where "Others" can be described.

If the Operating Agent discovers or is notified that several users enter the same term for "Others", this new term can be added to the roll-down menu. The project members will be informed about the change.

Changing or Removing a Choice from a Roll-Down Menu

Choices in roll-down menus could be changed or removed. However, this may lead to inconsistencies in already existing data. Therefore, this must be handled with care.

2. A CADAK Cable Ageing project member initiates removing or changing a choice in a roll-down menu by sending a request (e.g. by e-mail) to the Operating Agent.

The Operating Agent checks if this change/removal would lead to inconsistency in existing data. If inconsistency is discovered, the Operating Agent informs the requesting project member and asks for reconsideration of the change/remove request.

In the case that the requesting project member maintains the change/remove request, the Operating Agent takes it to the next Working Group meeting, where it is discussed and decided.

Changes of Database Items

Changes of database items are considered as major changes, and will always be discussed in Working Group meetings. Changes of database items include:

Adding new items
Deleting existing items
Changing type of an existing item
Changing required/optional status of an item

Changes of Description and User Instruction / Note of Database Items

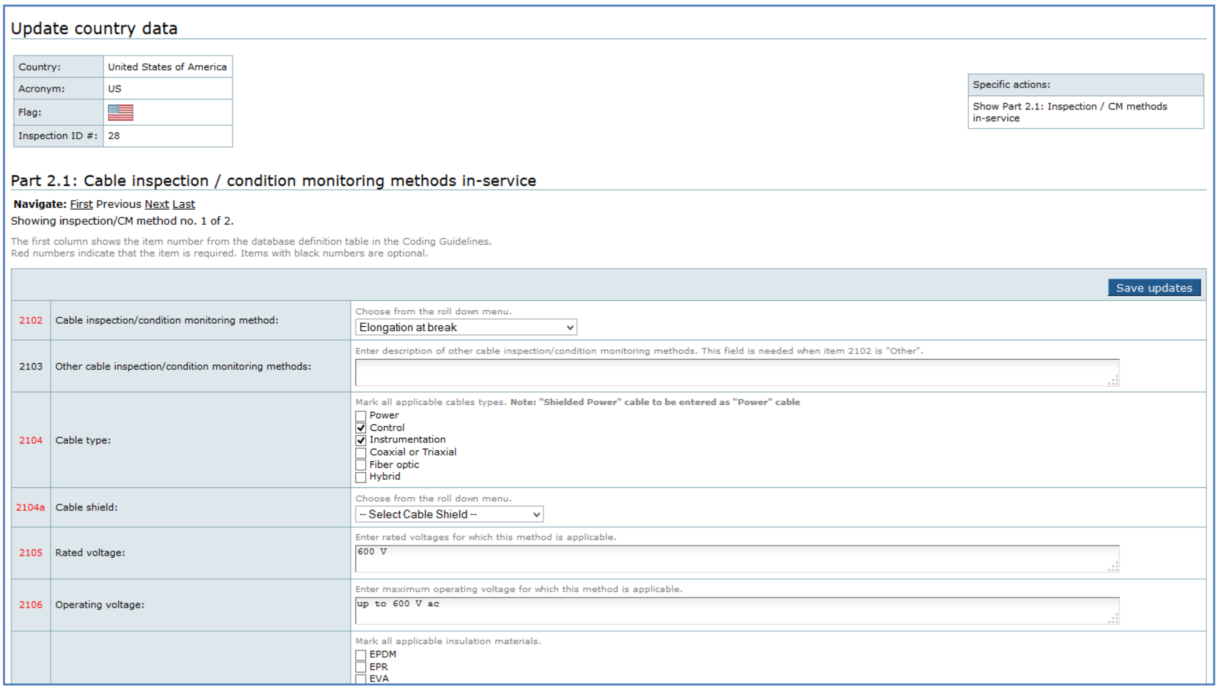
Changes of the columns "Description" and/or "User Instruction/Note" in the tables sheets can be performed by the Operating Agent, either on request from a CADAK Cable Ageing project member, or on the Operating Agent's own initiative.

All changes of this kind will be carefully considered by the Operating Agent before they are accomplished.

Changes to Database Content

Provided the User having sufficient access rights to the data in question, making changes to existing data can be obtained entering UPDATE mode, see example in Figure 6. Nevertheless, the SCAP Cable Ageing Working Group decided in its 7th meeting in September 2009 that changes to mandatory items, uniquely identifying a data record, must go through the Operating Agent, and they are not changeable from the table sheets. This provision has been continued in CADAK.

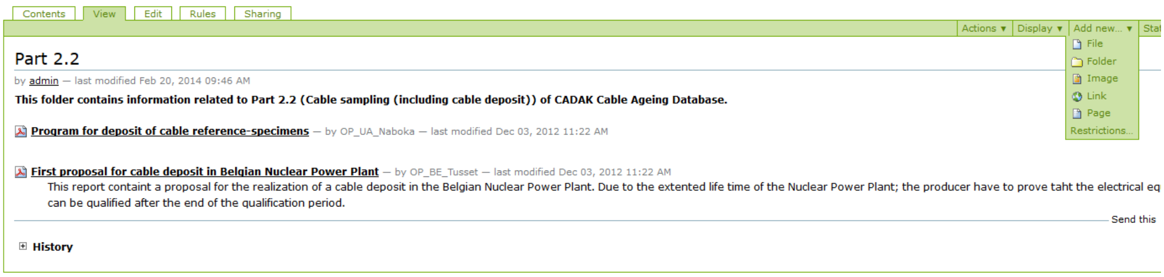
Figure 6: Example of record data in “UPDATE” mode (Part 2.1)



Creating the Knowledge Space

Adding new elements to the knowledge base is made from a type selection drop-down menu, subsequent to entering the actual part of “Knowledge Base”. Figure 6 shows an example of the “Add new…” drop-down menu.

Figure 7: Add new document files to Knowledge Base from a drop-down menu



Knowledge Data Retrieval

Once elements have been added to the knowledge base, they can be extracted by choosing from an element directory list. Figure 8 shows an example of an element list for Part 2.2, and Figure 9 shows an example of a chosen document file. Following the link will open the file.

Figure 8: Select document files for retrieval from the Part document list

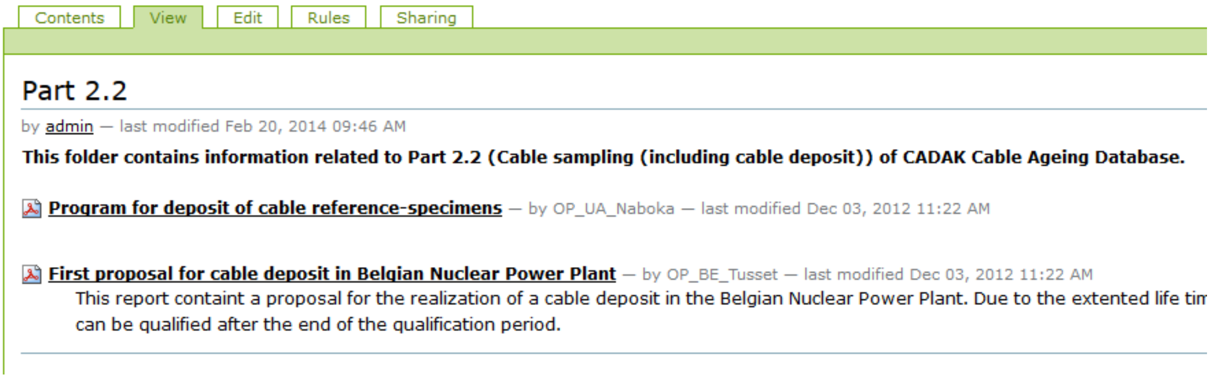


Figure 9: Document file selected – click link to open